SECTION 5.0

EMISSIONS OF LEAD AND LEAD COMPOUNDS FROM COMBUSTION SOURCES

This section contains process descriptions, available emission factor data, and source locations for source categories that emit lead and lead compounds during combustion. These source categories include fuel combustion in external and internal combustion engines; incineration of various types of waste, including municipal waste, industrial waste, sewage sludge, medical waste, hazardous waste, and scrap tires; and drum and barrel reclamation and crematories.

There are few emission controls that are dedicated solely to reducing lead emissions from combustion sources. However, the control strategies used to reduce PM emissions have been found to be effective in controlling lead emissions in particulate form. Where a specific emission control strategy has been identified to reduce lead emissions from a particular combustion source discussed in this section, that control strategy is discussed as part of the process description for that source. In many cases throughout this section, emission factor data are provided for both controlled and uncontrolled combustion units that are typically found in a particular source category.

5.1   STATIONARY EXTERNAL COMBUSTION

The combustion of solid, liquid, and gaseous fuels such as coal, wood, fuel oil, and natural gas has been shown to be a source of lead emissions. Lead emission rates depend on both fuel characteristics and combustion process characteristics. Emissions of lead originate from lead compounds contained in fuels and emitted during combustion.[51,52,53] Because metals such as lead only change forms (chemical and physical states) during combustion and are never destroyed, the

amount of lead in the original fuel or waste will be equal to the amount of lead found in the ash or emitted in the effluent gas.[54,55]

Lead concentrations in coal depend on the type of coal. Example specific lead concentrations in coal are as follows: anthracite coal contains approximately 7 ppm lead; bituminous coal contains 14 ppm lead; subbituminous coal contains 6 ppm lead; and lignite coal contains 7 ppm lead.[56] Likewise, the lead concentration in fuel oil also depends on the type of oil. Residual oil averages about 1 ppm lead by weight, while the lead content of distillate oil ranges from 0.1 to 0.5 ppm lead by weight.[57,58] Wood has been reported to have a lead content of 20 ppm.[59]

Lead and lead compound emissions may be reduced from combustion sources by using PM control devices, lower combustion and control device temperatures, and controlling feed chlorine content.[60] Each of these lead reduction techniques is discussed briefly below.

In general, use of PM control devices in combustion/air pollution control systems can be viewed as a surrogate for controlling emissions of lead (and other metals).[55] The most effective means of controlling lead emissions to the atmosphere are minimizing lead vaporization in the combustion zone and maximizing small particle collection in the Air Pollution Control Device (APCD). Lead compounds, like many heavy metal compounds, vaporize at elevated temperatures and, as temperatures drop, only a fraction of the vaporized metal condenses. The remaining vaporized metal can escape through the PM APCD.

During the combustion process, lead and other metals volatilize and then, upon cooling, condense on all available particulate surface area. The submicrometer particles with very high surface areas can carry a very high concentration of condensed lead. This phenomenon is known as "fine particle enrichment." There are three general factors favoring fine particle enrichment of lead:[55]

- High particulate surface area;

- Large number of particles; and

- Low flue gas temperatures.

There is some evidence that fine particle enrichment of lead on PM is not as prevalent at higher flue gas temperatures. It is believed that as long as the flue gas temperatures remain high, the metals tend to remain volatilized, such that they do not condense and bond with PM.[55]

Another factor that influences the extent of lead emissions is chlorine content. The chlorine content of the combusted fuel or waste increases the sensitivity of lead emissions to bed temperature. When a high chlorine content is present, lead will volatilize at lower temperatures due to the high volatility of lead chlorides ($PbCl_2$) versus oxides (PbO). Monitoring and limiting the feed chlorine content reduces the volatility of lead, allowing more lead to condense onto PM for more effective lead emissions control.

The primary stationary combustion sources emitting lead compounds are boilers, furnaces, heaters, stoves, and fireplaces used to generate heat and/or power in the residential, utility, industrial, and commercial use sectors. A description of combustion sources, typical emission control equipment, and lead emission factors for each of these major use sectors is provided in the sections that follow.

5.1.1   Source Location

Fuel economics and environmental regulations affect regional use patterns for combustion sources. Most of the utility coal-firing capability in the United States is east of the Mississippi River, with the significant remainder being in the Rocky Mountain region. Natural gas is used primarily in the South Central States and California. Oil is predominantly used in Florida and the Northeast. Information on precise utility plant locations can be obtained by contacting utility trade associations, such as the Electric Power Research Institute in Palo Alto, California (415-855-2000), the Edison Electric Institute in Washington, D.C. (202-828-7400), or the U.S. Department of Energy (DOE) in Washington, D.C. Publications by EPA and DOE on the utility industry are useful in determining specific facility locations, sizes, and fuel use.

Industrial and commercial coal combustion sources are located throughout the United States, but tend to be concentrated in areas of industry and larger population. Most of the coal-fired industrial boiler sources are located in the Midwest, Appalachian, and Southeast regions. Industrial wood-fired boilers tend to be located almost exclusively at pulp and paper, lumber products, and furniture industry facilities. These industries are concentrated in the Southeast, Gulf Coast, Appalachian, and Pacific Northwest regions. Trade associations such as the American Boiler Manufacturers Association in Arlington, Virginia and the Council of Industrial Boiler Owners in Fairfax Station, Virginia can provide information on industrial boiler locations and trends.[61,62]

Section 5.1.2 presents process descriptions and available emission factors for residential heating. Section 5.1.3 presents process descriptions for utility, industrial, and commercial fuel combustion. Section 5.1.4 presents available emission factors for utility, industrial, and commercial fuel combustion.

5.1.2   <u>Residential Heating</u>

The residential sector includes furnaces and boilers burning coal, oil, and natural gas, stoves and fireplaces burning wood, and kerosene heaters. All units in this sector are designed to heat individual homes. Residential combustion sources generally are not equipped with PM or gaseous pollutant control devices. With coal- and wood-fired residential sources, changes in stove design and operating practice in recent years have lowered PM, CO, and hydrocarbon emissions from these sources. Changes include modified combustion air flow control, greater thermal control and heat storage, and the use of combustion catalysts. Such changes are also expected to reduce lead emissions.[63,64]

Residential Coal Combustion

<u>Process Description</u>--Coal is not widely used for residential heating in the United States. Only 0.3 percent of the total coal consumption in 1990 was for residential use.[65]

Although combustion units burning coal are minor sources of lead emissions, they may be important local sources in areas where a large number of residences rely on coal for heating.

There are a wide variety of coal-burning stoves in use. These include boilers, furnaces, and stoves that are designed to burn coal, and wood-burning stoves that burn coal. These units may be either hand-fed or automatically-fed. Boilers and warm-air furnaces are usually stoker-fed and are automatically controlled by a thermostat. Stoves are less sophisticated, generally hand-fed, and less energy efficient than boilers and furnaces. Lead emissions from all of these units depend on the concentration of lead in the coal.

Emissions--A 1979 EPA study reported average lead emission factors for a residential coal-burning boiler and furnace. These emission factors, shown in Table 5-1, represent total lead particulate emissions. Although these factors are dated, they should be representative of current lead emissions from these sources for two reasons. First, these emissions depend on the concentration of lead in the coal used and, second, emission controls still remain uncommon among these sources.[66]

Residential Distillate Oil Combustion

Process Description--Distillate oil is the second most important home heating fuel behind natural gas. (Residual oil is seldom used in the residential sector.)[67] The use of distillate oil-fired heating units is concentrated in the Northeast. In 1991, Connecticut, Maine, Massachusetts, New Hampshire, Rhode Island, Vermont, Delaware, District of Columbia, Maryland, New Jersey, New York, and Pennsylvania accounted for approximately 72 percent of residential distillate oil sales.[68]

Residential oil-fired heating units are available in a number of design and operating variations. These variations include burner and combustion chamber design, excess air, and heating medium. Residential systems typically operate only in an "on" or "off" mode and at a constant fuel-firing rate, unlike commercial and industrial applications, where load modulation is the general practice.[70] In distillate oil-fired heating units, fuel oil is atomized into

TABLE 5-1. LEAD EMISSION FACTORS FOR RESIDENTIAL COAL COMBUSTION

SCC Number	Emission Source	Control Device	Average Emission Factor in lb/ton (kg/Mg)[a]	Emission Factor Range in lb/ton (kg/Mg)[a]	Emission Factor Rating
A21-04-002-000	Bituminous/ Subbituminous Coal - All Combustor Types	None	2.00×10^{-2} (1.00×10^{-2})	---	U
A21-04-001-000	Anthracite Coal - All Combustor Types	None	1.60×10^{-2} (8.00×10^{-3})	---	U

Source: Reference 69

[a] Emission factors are expressed in lb (kg) of pollutant emitted per ton (Mg) of coal combusted.

"---" means data are not available.

finer droplets for combustion. Finer droplets generally result in more complete combustion and less PM formation.

Emissions--Lead emissions from oil combustion depend primarily on the grade, composition of the fuel, and the level of equipment maintenance. Secondary contributions would be the type and size of the combustion equipment and the firing and loading practices used. The extent of particulate and lead emissions depends directly on the grade of oil fired. The lighter distillate oils result in significantly lower particulate formation than do the heavier and dirtier residual oils. In addition, residual oils typically contain substantially higher lead levels than do distillate oils.

Residential combustion units are less sophisticated than utility and industrial combustion units. For this reason, they normally burn distillate oil to keep emissions to a minimum.[57,58] Average emission factors for residential distillate oil-fired furnaces are presented in Table 5-2.

Residential Natural Gas Combustion

Process Description--Natural gas is the most widely used fuel for home heating purposes. More than half of all homes in the United States are heated by natural gas combustion.[71] Gas-fired residential heating systems are generally less complex and easier to maintain than oil-burning units because the fuel burns cleaner and no atomization is required. Residential gas burners typically are built of the same basic design. Natural aspiration is used where the primary air mixes with the gas as it passes through the distribution pipes. Secondary air enters the furnace around the burners. Flue gases then pass through a heat exchanger and a stack. As with oil-fired systems, there is usually no APCD installed on gas systems. Excess air, residence time, flame retention devices, and maintenance are the key factors in controlling PM (including lead) emissions from these units.

Emissions--Emissions testing data for lead from gas-fired residential units have been extremely scarce, probably because the expected emissions are low and this source has not

TABLE 5-2. EMISSION FACTORS FOR RESIDENTIAL DISTILLATE OIL-FIRED FURNACES

SCC Number	Emission Source	Control Device	Average Emission Factor in lb/MMBtu (kg/Joule)[a]	Emission Factor Range in lb/MMBtu (kg/Joule)[a]	Emission Factor Rating
A21-04-004-000	Distillate (No. 2 oil) Oil-fired Furnaces	None	2.2×10^{-4} (9.5×10^{-14})	2.44×10^{-2} - 3.08×10^{-2} $(2.92 \times 10^{-6}$ - $3.96 \times 10^{-6})$	U

Source: Reference 72

[a] Emission factors are expressed in lb (kg) of pollutant emitted per MMBtu (Joule) of heat input.

been identified as a priority for testing. As a result, there are no available emission factors for this source.

5.1.3   <u>Process Descriptions for Utility, Industrial, and Commercial Fuel Combustion</u>

Utility Sector

Utility boilers burn coal, oil, natural gas, and wood to generate steam for electricity generation. Fossil fuel-fired utility boilers comprise about 72 percent [or 497,000 megawatts (MW)] of the generating capacity of U.S. electric power plants. Of these fuels, coal is the most widely used, accounting for approximately 60 percent of the U.S. fossil fuel-powered electricity generating capacity. Natural gas represents about 25 percent and oil represents the remaining 15 percent.[73]

A utility boiler consists of several major subassemblies, as shown in Figure 5-1. These subassemblies include the fuel preparation system, air supply system, burners, the furnace, and the convective heat transfer system. The fuel preparation system, air supply, and burners are primarily involved in converting fuel into thermal energy in the form of hot combustion gases. The last two subassemblies transfer the thermal energy in the combustion gases to the superheated steam that operates the steam turbine and produces electricity.[73]

Utility boilers are generally identified by their furnace configuration. Different furnace configurations used in utility boilers include tangentially-fired, wall-fired, cyclone-fired, stoker-fired, and fluidized bed combustion (FBC) boilers. Some of these furnace configurations are designed primarily for coal combustion, while others are also used for oil or natural gas combustion. The furnaces types most commonly used for firing oil and natural gas are the tangentially-fired and wall-fired boiler designs.[74] Each of these furnace types is described below.

<u>Tangentially-fired Boiler</u>--The tangentially-fired boiler is based on the concept of a single flame zone within the furnace. The fuel-air mixture in a tangentially-fired boiler projects from the four corners of the furnace along a line tangential to an imaginary cylinder located
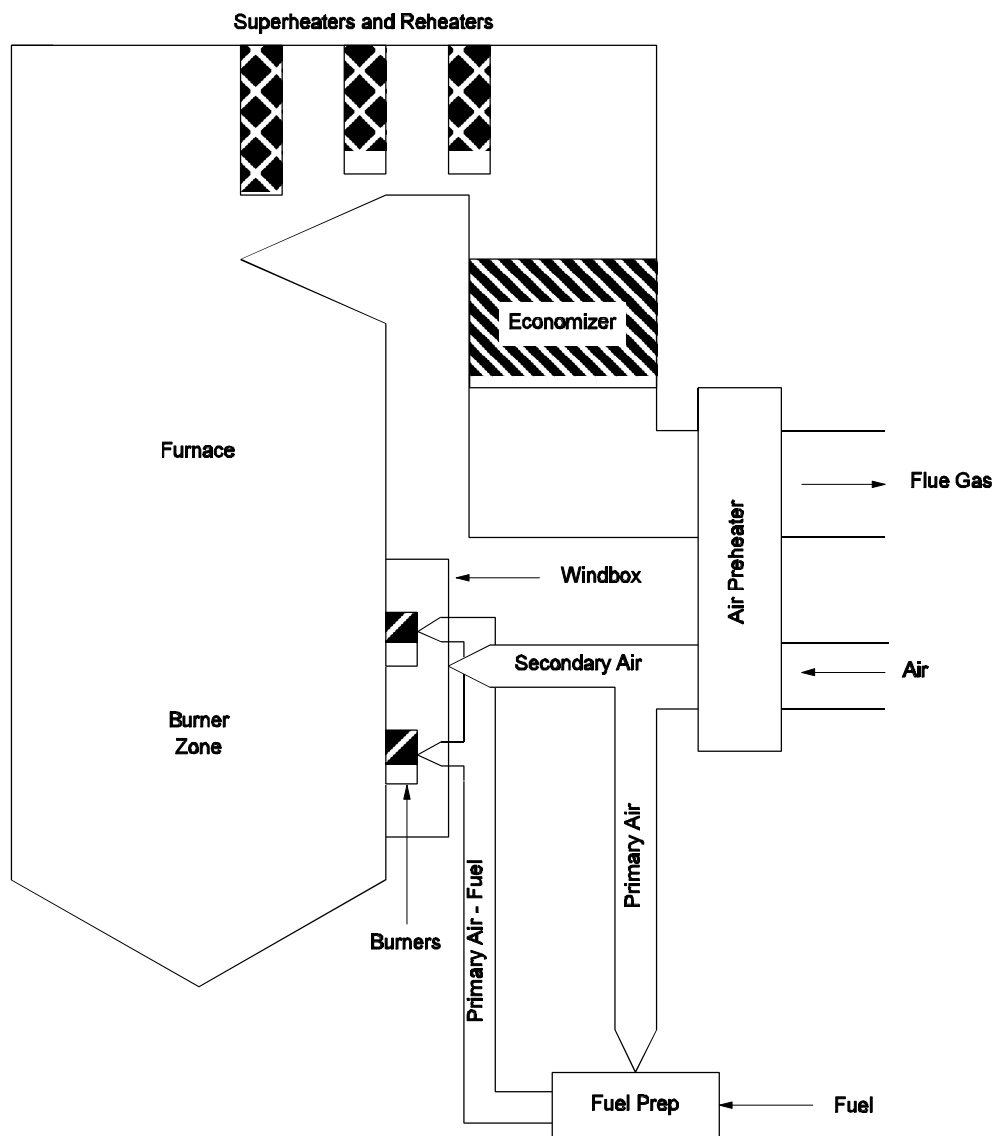
Figure 5-1. Simplified Boiler Schematic

Source: Reference 73.

along the furnace centerline. When coal is used as the fuel, the coal is pulverized in a mill to the consistency of talcum powder (i.e., so that at least 70 percent of the particles will pass through a 200 mesh sieve), entrained in primary air, and fired in suspension.[75] As fuel and air are fed to the burners, a rotating "fireball" is formed. By tilting the fuel-air nozzle assembly, this "fireball" can be moved up and down to control the furnace exit gas temperature and to provide steam temperature control during variations in load. Tangentially-fired boilers commonly burn (pulverized) coal. However, oil or gas may also be burned.[73]

Wall-fired Boiler--The wall-fired boiler, or normal-fired boiler, is characterized by multiple, individual burners located on a single wall or on opposing walls of the furnace (Figure 5-2). As with tangentially-fired boilers, when coal is used as the fuel it is pulverized, entrained in primary air, and fired in suspension. In contrast to tangentially-fired boilers that produce a single flame zone, each of the burners in a wall-fired boiler has a relatively distinct flame zone. Various wall-fired boiler types exist, including single-wall, opposed-wall, cell, vertical, arch, and turbo. Wall-fired boilers may burn (pulverized) coal, oil, or natural gas.[73]

Cyclone-fired Boiler--In the cyclone-fired boiler, fuel and air are burned in horizontal, cylindrical chambers, producing a spinning, high-temperature flame. Cyclone-fired boilers are almost exclusively (crushed) coal-fired. The coal is crushed to a 4-mesh size and admitted with the primary air in a tangential fashion. The finer coal particles are burned in suspension, while the coarser particles are thrown to the walls by centrifugal force.[74] Some units are also able to fire oil and natural gas.[73]

Fluidized Bed Combustion Boiler--Fluidized bed combustion is a newer boiler technology that is not as widely used as the other, more conventional boiler types. In a typical FBC, crushed coal in combination with inert material (sand, silica, alumina, or ash) and/or sorbent (limestone) are maintained in a highly turbulent suspended state by the upward flow of primary air (Figure 5-3). This fluidized state promotes uniform and efficient combustion at lower furnace temperatures, between 1,575 and 1,650°F (860 and 900°C), compared to 2,500 and 2,800°F (1,370 and 1,540°C) for conventional coal-fired boilers. Fluidized bed combustors have been developed to operate at both atmospheric and pressurized conditions.[73]
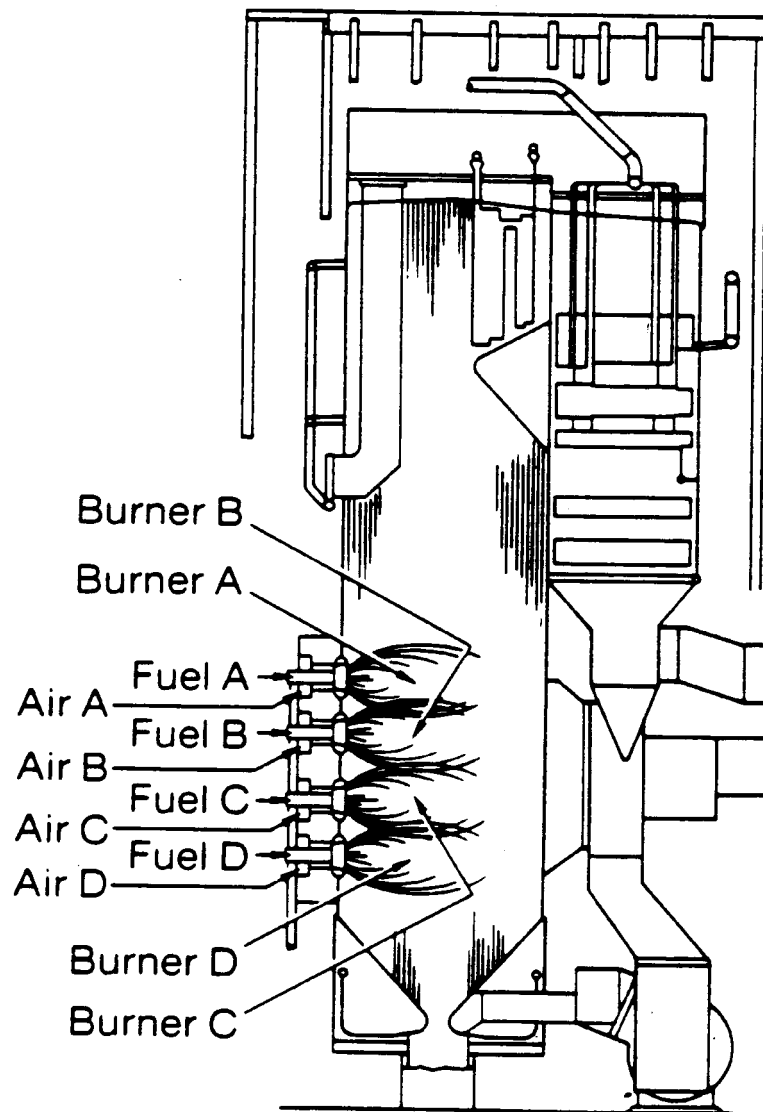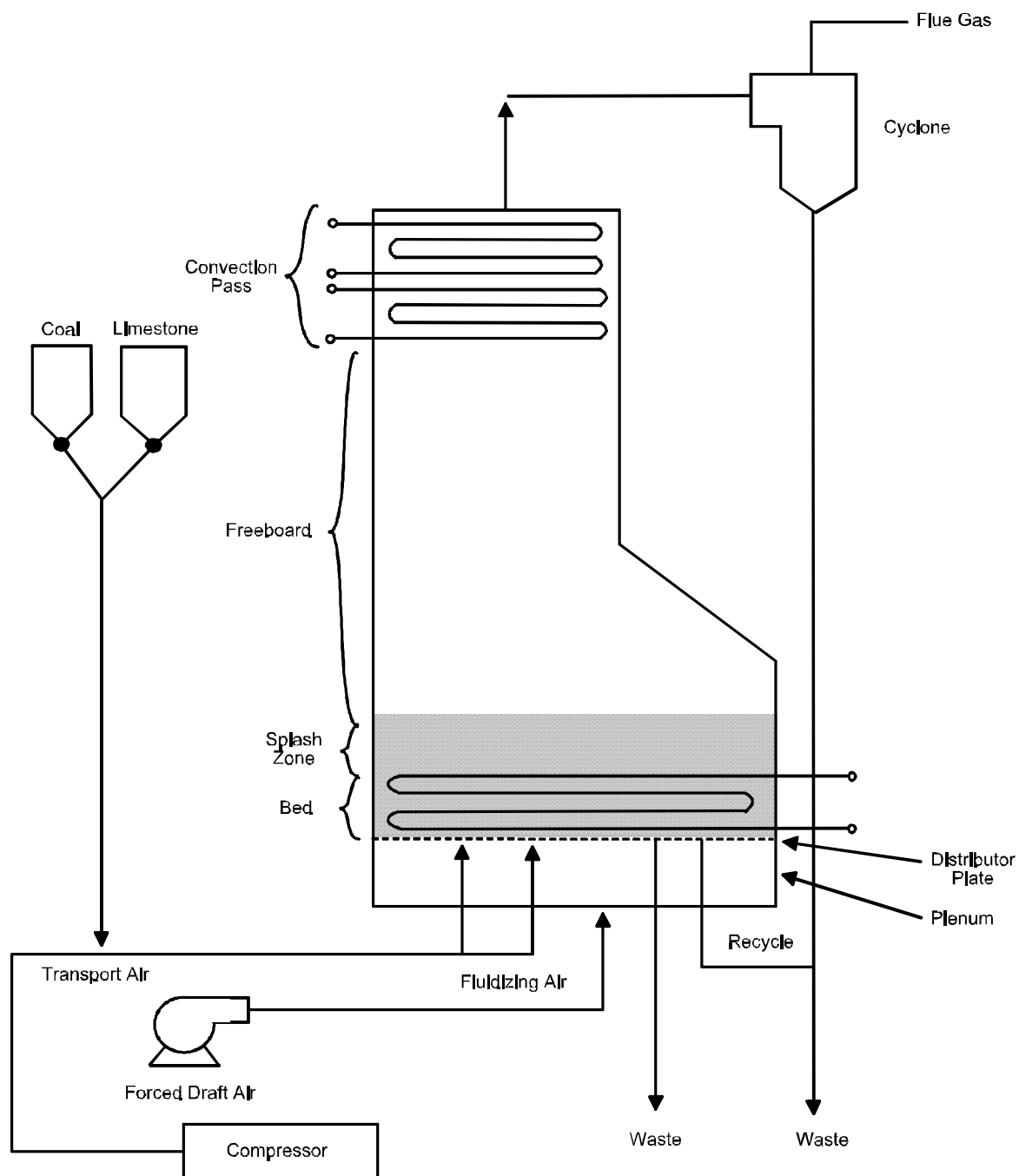
Figure 5-2. Single Wall-fired Boiler

Source: Reference 73.

Figure 5-3. Simplified Atmospheric Fluidized Bed Combustor Process Flow Diagram

Source: Reference 73.

Stoker-fired Boiler--Instead of firing coal in suspension as in the boilers described above, the mechanical stoker can be used to burn coal in fuel beds. Mechanical stokers are designed to feed coal onto a grate within the furnace. The most common stoker type used in the utility industry is the spreader stoker (Figure 5-4). In the spreader stoker, a flipping mechanism throws crushed coal into the furnace and onto a moving fuel bed (grate). Combustion occurs partly in suspension and partly on the grate.[75]

Emission Control Techniques--Utility boilers are highly efficient and are among the best controlled of all combustion sources. Existing emission regulations for total PM have necessitated controls on coal- and oil-fired utility sources. Emission controls are not required on natural gas boilers because, relative to coal and oil units, uncontrolled emissions are inherently low.[64] Baghouses, ESPs, wet scrubbers, and multicyclones have been used to control PM in the utility sector. As described in other source category sections, lead condenses on PM, which is easily controlled by PM control technologies. Particulate lead, specifically fine particulate, is controlled most effectively by baghouses or ESPs. Depending on their design, wet scrubbers are potentially effective in controlling particulate lead. Multicyclones are ineffective at capturing fine particles of lead and, therefore, are a poor control system for lead emissions.[63,64]

Lead emissions from utility boilers are commonly controlled using an SO_2 control technology known as lime/limestone flue gas desulfurization (FGD). This technology employs a wet scrubber for SO_2 removal and is often preceded by an ESP, which accomplishes the bulk of PM control. Wet FGD/ESP systems, while controlling lead condensed on PM at the entrance to the ESP, are relatively inefficient for control of vapor-phase lead. However, most lead emissions are condensed on PM and are not emitted in the vapor phase.[63,64]

A more recently applied SO_2 control technique for utility boilers is spray drying. In this process, the gas stream is cooled in the spray dryer, but it remains above the saturation temperature. A fabric filter or an ESP is located downstream of the spray dryer, thus controlling both particulate-phase lead emissions and vapor-phase lead emissions that condense before they reach the baghouse or ESP.[63,64]
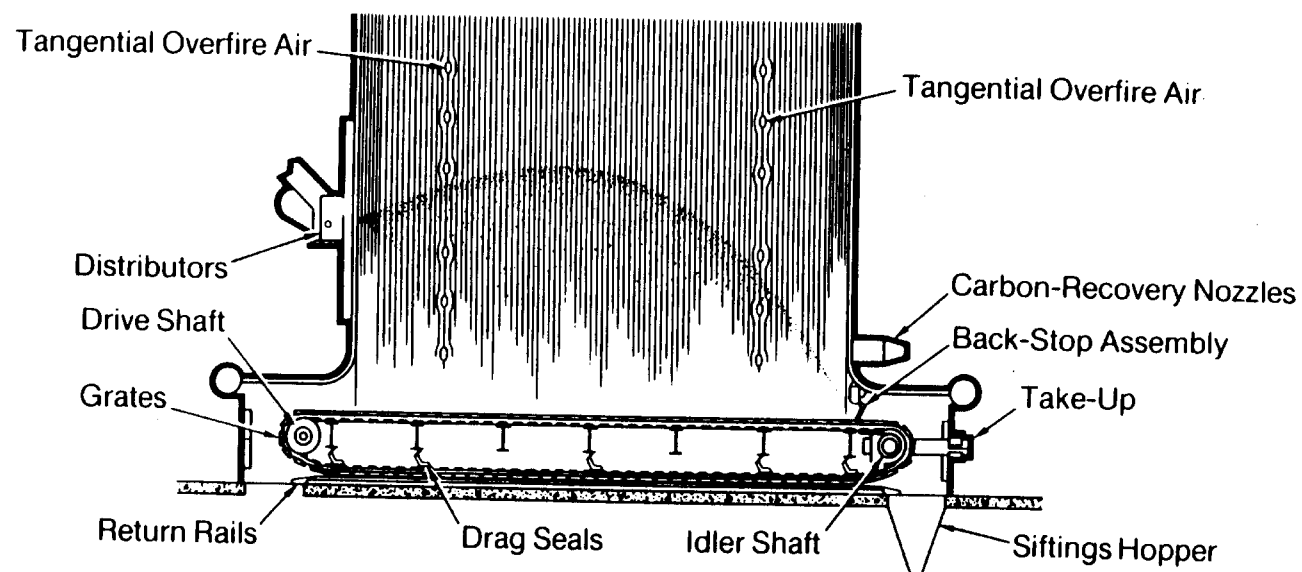
Figure 5-4. Spreader Type Stoker-fired Boiler

Industrial/Commercial Sector

Industrial boilers are widely used in manufacturing, processing, mining, and refining, primarily to generate process steam, electricity, or space heat at the facility. Only a limited amount of electricity is generated by the industrial sector; only 10 to 15 percent of industrial boiler coal consumption and 5 to 10 percent of industrial boiler natural gas and oil consumption are used for electricity generation.[76] Commercial boilers are used to provide space heating for commercial establishments, medical institutions, and educational institutions.

In collecting survey data to support its Industrial Combustion Coordinated Rulemaking (ICCR), the EPA compiled information on a total of 69,494 combustion boiler units in the industrial and commercial sectors.[259] While this number likely underestimates the total population of boilers in the industrial and commercial sectors (due to unreceived survey responses and lack of information on very small units) it provides an indication of the large number of sources included in this category.

Of the units included in the ICCR survey database, approximately 70% were classified in the natural gas fuel subcategory, 23% in the oil (distillate and residual) subcategory, and 6% in the coal burning subcategory. These fuel subcategory assignments are based on the units burning only greater than 90% of the specified fuel for that subcategory. All other units (accounting for the other 1% of assignments) are assigned to a subcategory of "other fossil fuel."[259]

Other fuels burned in industrial boilers are wood wastes, liquified petroleum gas, and kerosene. Wood waste is the only non-fossil fuel discussed here since most lead emissions are attributed to the combustion of wood fuel. The burning of wood waste in boilers is confined to those industries where it is available as a by-product. It is burned both to obtain heat energy and to alleviate possible solid waste disposal problems. Generally, bark is the major type of wood waste burned in pulp mills. In the lumber, furniture, and plywood industries, either a mixture of wood and bark, or wood alone, is frequently burned. As of 1980, the most recent data identified,

there were approximately 1,600 wood-fired boilers operating in the United States with a total capacity of over 100,000 MMBtu/hr (30,000 MW thermal).[78]

Many of the same boiler types used in the utility sector are also used in the industrial/commercial sector; however, the average size boiler used in the industrial/ commercial sector is substantially smaller than the average size boiler used in the utility sector. In addition, a few boiler designs are used only by the industrial/commercial sector. For a general description of the major subassemblies and key thermal processes that occur in boilers, refer to Figures 5-1 to 5-4 in the section on Utility Sector Process Description and the accompanying discussion.

Stoker-fired Boiler--Instead of firing coal in suspension (like the boilers described in the Utility Sector Process Description section), mechanical stokers can be used to burn coal in fuel beds. All mechanical stokers are designed to feed coal onto a grate within the furnace. The most common stoker types in the industrial/commercial sector are overfeed and underfeed stokers. In overfeed stokers, crushed coal is fed from an adjustable gate above onto a traveling or vibrating grate below. The crushed coal burns on the fuel bed as it progresses through the furnace. Conversely, in underfeed stokers, crushed coal is forced upward onto the fuel bed from below by mechanical rams or screw conveyors.[73,75]

Water-tube Boilers--In water-tube boilers, water is heated as it flows through tubes surrounded by circulating hot gases. These boilers represent the majority (i.e., 57 percent) of industrial and commercial boiler capacity (70 percent of industrial boiler capacity).[76] Water-tube boilers are used in a variety of applications, from supplying large amounts of process steam to providing space heat for industrial and commercial facilities. These boilers have capacities ranging from 9.9 to 1,494 MMBtu/hr (2.9 to 439.5 MW thermal), averaging about 408 MMBtu/hr (120 MW thermal). The most common types of water-tube boilers used in the industrial/commercial sector are wall-fired and stoker-fired boilers. Tangentially-fired boilers and FBC boilers are less commonly used.[77] Refer to Figures 5-1 to 5-4 and the accompanying discussion in the section on Utility Sector Process Description for more detail on these boiler designs.

Fire-tube and Cast Iron Boilers--Two other heat transfer methods used in the industrial/commercial sector are fire-tube and cast iron boilers. In fire-tube boilers, hot gas flows through tubes that are surrounded by circulating water. Fire-tube boilers are not available with capacities as large as water-tube boilers, but they are also used to produce process steam and space heat. Most fire-tube boilers have a capacity between 1.4 and 25 MMBtu/hr (0.4 to 7.3 MW thermal). Most installed fire-tube boilers burn oil or gas and are used primarily in commercial/institutional applications.[77]

In cast iron boilers, the hot gas is also contained inside the tubes that are surrounded by the water being heated, but the units are constructed of cast iron instead of steel. Cast iron boilers are limited in size and are used only to supply space heat. Cast iron boilers range in size from less than 0.34 to 9.9 MMBtu/hr (0.1 to 2.9 MW thermal).[77]

Wood Waste Boilers--The burning of wood waste in boilers is primarily confined to those industries where wood is available as a by-product. Wood is burned both to obtain heat energy and to alleviate solid waste disposal problems. Wood waste may include large pieces such as slabs, logs, and bark strips as well as cuttings, shavings, pellets, and sawdust.[78]

Various boiler firing configurations are used to burn wood waste. One configuration that is common in smaller operations is the dutch oven or extension type of furnace with a flat grate. This unit is used widely because it can burn very high-moisture fuels. Fuel is fed into the oven through apertures in a firebox and is fired in a cone-shaped pile on a flat grate. The burning is accomplished in two stages: (1) drying and gasification, and (2) combustion of gaseous products. The first stage takes place in a cell separated from the boiler section by a bridge wall. The combustion stage takes place in the main boiler section.[78]

In another type of boiler, the fuel-cell oven, fuel is dropped onto suspended fixed grates and is fired in a pile. The fuel cell uses combustion air preheating and positioning of secondary and tertiary air injection ports to improve boiler efficiency.[78]

In many large operations, more conventional boilers have been modified to burn wood waste. These modified units may include spreader stokers with traveling grates or vibrating grate stokers, as well as tangentially-fired or cyclone-fired boilers. Refer to Figures 5-1 to 5-4 and the accompanying discussion in the section on <u>Utility Sector Process Description</u> for more detail on these types of boilers. The spreader stoker, which can burn dry or wet wood, is the most widely used of these configurations. Fuel is dropped in front of an air jet that casts the fuel out over a moving grate. The burning is carried out in three stages: (1) drying, (2) distillation and burning of volatile matter, and (3) burning of fixed carbon. These operations often fire natural gas or oil as auxiliary fuel. Firing an auxiliary fuel helps to maintain constant steam when the wood supply fluctuates or to provide more steam than can be generated from the wood supply alone.[78]

Sander dust is often burned in various boiler types at plywood, particle board, and furniture plants. Sander dust contains fine wood particles with a moisture content of less than 20 percent by weight. The dust is fired in a flaming horizontal torch, usually with natural gas as an ignition aid or as a supplementary fuel.[78]

A recent development in wood-firing is the FBC (refer to Figures 5-1 to 5-4 and the accompanying discussion in <u>Utility Sector Process Description</u> for more detail on this boiler type). Because of the large thermal mass represented by the hot inert bed particles, FBCs can handle fuels with high moisture content (up to 70 percent, total basis). Fluidized bed combustors can also handle dirty fuels (up to 30 percent inert material). Wood material is pyrolyzed faster in a fluidized bed than on a grate due to its immediate contact with hot bed material.[78]

The composition of wood waste is expected to have an impact on lead emissions. The composition of wood waste depends largely on the industry from which it originates. Wood waste fuel can contain demolition debris like plastics, paint, creosote-treated wood, glues, synthetics, wire, cable, insulation, etc., which are potential sources of lead emissions. Pulping operations, for example, produce great quantities of bark along with sand and other noncombustibles. In addition, when fossil fuels are co-fired with wood waste, there is potential for additional lead emissions from the lead content of the fossil fuel.[79]

Waste Oil Combustion--Waste oil is another type of fuel that is burned primarily in small industrial/commercial boilers and space heaters. Space heaters (small combustion units generally less than 250,000 Btu/hr [0.1 MW] heat input) are common in automobile service stations and automotive repair shops where supplies of waste crankcase oil are available.[80] Waste oil includes used crankcase oils from automobiles and trucks, used industrial lubricating oils (such as metal working oils), and other used industrial oils (such as heat transfer fluids). Due to a breakdown of the physical properties of these oils and contamination by other materials, these oils are considered waste oils when they are discarded.[81]

The federal government has developed regulations for waste oil fuel under the Resource Conservation and Recovery Act (RCRA). The EPA has determined that as long as used oil is recycled (which includes burning it for energy recovery as well as re-refining it or other processes), it is not considered a hazardous waste under RCRA 40 CFR 261.1.[82] However, if a facility does burn used oil, that facility is subject to certain requirements under RCRA.

EPA has established two categories of waste fuel: "on-specification" and "off-specification." If the lead levels of the waste oil are 100 ppm or less, the waste oil is classified as "on-specification;" if the lead levels are greater than 100 ppm, the waste oil is classified as "off-specification" (40 CFR 279.11).[83]

If a facility is burning "on-specification" waste oil for energy recovery, that facility is only subject to certain reporting and recordkeeping requirements (40 CFR 279.11).[86] If a facility burns the waste oil in a space heater with heat input capacity less than 0.5 million Btu/hr (0.15 Mg) and vents the exhaust to the ambient air, that facility is not subject to any requirements (40 CFR 279.23).[84]

A facility burning "off-specification" waste oil for energy recovery must comply with additional requirements, including verification to EPA that the combusted oil was not mixed with other hazardous wastes (40 CFR Subpart G).[88]

Boilers designed to burn No. 6 (residual) fuel oils or one of the distillate fuel oils can be used to burn waste oil, with or without modifications for optimizing combustion. As an alternative to boiler modification, the properties of waste oil can be modified by blending it with fuel oil to the extent required to achieve a clean-burning fuel mixture.

Coal Combustion--A very small amount of coal is used in the industrial/commercial sector. Coal accounts for only 18 percent of the total firing capacity of fossil fuel used. The majority of coal combustion occurs in the utility sector. Refer to Figures 5-1 to 5-4 and the accompanying discussion in Utility Sector Process Description for more detail about these boiler types.

Emission Control Techniques--The amount of lead emissions from industrial/commercial boilers depends primarily on two factors: (1) the type of fuel burned, and (2) the type of boiler used. The secondary influences on lead emissions are the operating conditions of the boiler and the APCD used.

Fly ash injection, one type of control commonly used in large wood-fired boilers to improve fuel efficiency, may increase particulate lead emissions. With fly ash injection, a greater amount of carbon is introduced into the boiler which, in turn, increases the amount of fine PM. Fine PM is more difficult to collect with the APCD; the fine PM escapes through the APCD uncontrolled, thereby increasing lead emissions.[75]

Emission controls for industrial boilers and their effectiveness in reducing lead emissions are very similar to those previously described for utility boilers. PM control in the industrial sector is achieved with baghouses, ESPs, wet scrubbers, and multicyclones. FGD systems for SO_2 control are used less frequently in the industrial sector than in the utility sector. Generally, in the industrial sector, SO_2 regulations are met by burning lower-sulfur-content fuels.[63,64]

PM emissions from oil-fired industrial boilers generally are not controlled under existing regulations because emission rates are low. Some areas may limit SO_2 emissions from

oil-firing by specifying the use of lower-sulfur-content oils. Natural gas-fired industrial boilers are also generally uncontrolled because of very low emissions.[63,64]

Wood-fired industrial boilers are typically controlled by multicyclones followed by venturi or impingement-type wet scrubbers for PM control. Some wood-fired boilers use ESPs for PM control. The effect of both control systems on lead emissions reduction is estimated to be similar to that obtained at coal-fired units using the same technology (i.e., potentially effective PM and vaporous lead control with scrubbers, and effective PM lead control but no vaporous lead control with ESPs).[63,64]

5.1.4   Emission Factors for Utility, Industrial, and Commercial Fuel Combustion

Extensive lead emissions data for utility, industrial, and commercial stationary external combustion sources are available in the literature. Because state and federal air pollution regulations often require emissions testing for toxic air pollutants, a current database of lead emissions from these fuel combustion sources exists.

Emission factors for utility, industrial, and commercial stationary external combustion source categories, grouped according to the type of fuel burned, are presented in Tables 5-3 to 5-19 and discussed under the following sub-headings:

- Wood waste combustion:

  -- Utility boilers (Table 5-3),

  -- Industrial boilers (Table 5-4),

  -- Commercial/institutional boilers (Table 5-5);

- Natural gas combustion:

  -- Utility boilers (Tables 5-6 and 5-7);

- Coal combustion:

  -- Utility boilers (Tables 5-8 and 5-9),

  -- Industrial boilers (Table 5-10),

  -- Commercial/institutional boilers (Table 5-11);

- Oil combustion:

  -- Utility boilers (Table 5-12 and 5-13),

  -- Industrial boilers (Table 5-14),

  -- Commercial/institutional boilers (Table 5-15);

- Waste oil combustion:

  -- Industrial boilers (Table 5-16),

  -- Commercial/institutional boilers (Table 5-17);

- Solid waste combustion:

  -- Utility boilers (Table 5-18);

- Miscellaneous combustion:

  -- Industrial boilers (Table 5-19).

Wood Waste Combustion

Lead emission factors for wood waste combustion in utility, industrial, and commercial boilers are presented in Tables 5-3, 5-4, and 5-5, respectively. These emission factors are widely applicable to all utility, industrial, and commercial wood waste combustion SCC categories.[73] However, a wide range of boiler sizes, boiler and control device configurations, and fuel characteristics is reflected by these composite emission factors. For this reason, if site-specific information is available to characterize an individual combustion source more accurately, it is recommended that the reader locate the appropriate process-specific emission factor presented in the applicable table.

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TABLE 5-3. LEAD EMISSION FACTORS FOR WOOD WASTE-FIRED UTILITY BOILERS

SCC Number	Emission Source	Control Device	Average Emission Factor in lb/ton (kg/Mg)[a]	Emission Factor Range in lb/ton (kg/Mg)[a]	Emission Factor Rating	Reference
1-01-009-01	Wood Waste-fired Boiler (Bark-fired)	None	2.90×10^{-3} (1.45×10^{-3})	---	D	86
1-01-009-02	Wood Waste-fired Boiler (Wood/Bark-fired)	ESP	1.60×10^{-5} (8.00×10^{-6})	---	D	86
		Scrubber	3.50×10^{-4} (1.75×10^{-4})	---	D	86
		Multiple Cyclone with Flyash Reinjection	3.20×10^{-4} (1.60×10^{-4})	---	D	86
		Multiple Cyclone without Flyash Reinjection	3.20×10^{-4} (1.60×10^{-4})	---	D	86
1-01-009-03	Wood Waste-fired Boiler (Wood-fired)	ESP	1.10×10^{-3} (5.50×10^{-4})	---	D	86
		Multiple Cyclone without Flyash Reinjection	3.10×10^{-4} (1.55×10^{-4})	---	D	86
		None	2.9×10^{-3} (1.45×10^{-3})	---	U	87
		Limestone Injection, Thermal de- NO_x with Ammonia Injection, Water Treatment, Multi-Cyclone, Fabric Collector	4.49×10^{-6} lb/MMBtu[b] $(1.93 \times 10^{-15}$ kg/Joule)	1.4×10^{-7} - 9.41×10^{-6} lb/MMBtu[b] $(6.00 \times 10^{-17}$ - 4.10×10^{-15} kg/Joule)	U	88

[a] Emission factors are expressed in lb (kg) of pollutant emitted per ton (Mg) of wood waste combusted, except as noted. Emission factors are based on wet, as-fired wood waste with 50 percent moisture and a higher heating volume of 4,500 Btu/lb.
[b] Emission factors are expressed in lb (kg) of pollutant emitted per MMBtu (Joule) of heat input.

"---" means data are not available.
ESP = Electrostatic Precipitator.

TABLE 5-4. LEAD EMISSION FACTORS FOR WOOD WASTE-FIRED INDUSTRIAL BOILERS

SCC Number	Emission Source	Control Device	Average Emission Factor in lb/ton (kg/Mg)[a]	Emission Factor Range in lb/ton (kg/Mg)	Emission Factor Rating	Reference
1-02-009-01	Wood Waste-fired Boiler (Bark-fired, >50,000 lb steam)	ESP - Medium Efficiency	1.50×10^{-6} lb/MMBtu[b] (6.46×10^{-16} kg/Joule)	1.30×10^{-6} - 1.70×10^{-6} lb/MMBtu[b] (5.60×10^{-16} - 7.33×10^{-16} kg/Joule)	U	89
		None	2.90×10^{-3} (1.45×10^{-3})	---	D	86
1-02-009-02	Wood Waste-fired Boiler (Wood/Bark-fired, >50,000 lb steam)	Multiple Cyclone with Flyash Reinjection	3.20×10^{-4} (1.60×10^{-4})	---	D	86
		ESP	1.60×10^{-5} (8.00×10^{-6})	---	D	86
		Scrubber	3.50×10^{-4} (1.75×10^{-4})	---	D	86
		Multiple Cyclone without Flyash Reinjection	3.20×10^{-4} (1.60×10^{-4})	---	D	86
1-02-009-03	Wood Waste-fired Boiler (Wood-fired, >50,000 lb steam)	Wet Scrubber - Medium Efficiency	1.60×10^{-5} lb/MMBtu[b] (6.89×10^{-15} kg/Joule)	1.10×10^{-5} - 2.50×10^{-5} lb/MMBtu[b] (4.74×10^{-15} - 1.08×10^{-14} kg/Joule)	U	90
		Multiple Cyclone without Flyash Reinjection/Wet Scrubber - Medium Efficiency	4.00×10^{-5} lb/MMBtu[b] (1.72×10^{-14} kg/Joule)	3.20×10^{-4} - 5.00×10^{-4} lb/MMBtu[b] (1.38×10^{-13} - 2.15×10^{-13} kg/Joule)	U	91
		Multiple Cyclone without Flyash Reinjection	3.10×10^{-4} (1.55×10^{-4})	---	D	86
		ESP	1.10×10^{-3} (5.50×10^{-4})	---	D	86

TABLE 5-4. LEAD EMISSION FACTORS FOR WOOD WASTE-FIRED INDUSTRIAL BOILERS (CONTINUED)

SCC Number	Emission Source	Control Device	Average Emission Factor in lb/ton (kg/Mg)[a]	Emission Factor Range in lb/ton (kg/Mg)	Emission Factor Rating	Reference
1-02-009-03 (continued)	Wood Waste-fired Boiler (Wood-fired, >50,000 lb steam)	Multiple Cyclone without Flyash Reinjection/ESP - Medium Efficiency	2.25×10^{-6} lb/MMBtu[b] (9.70×10^{-16} kg/Joule)	2.10×10^{-6} - 2.40×10^{-6} lb/MMBtu[b] (9.05×10^{-16} - 1.03×10^{-15} kg/Joule)	U	92
1-02-009-04	Wood Waste-fired Boiler (Bark-fired, <50,000 lb steam)	None	2.90×10^{-3} (1.45×10^{-3})	---	D	86
1-02-009-05	Wood Waste-fired Boiler (Wood/Bark-fired, <50,000 lb steam)	Multiple Cyclone with Flyash Reinjection	3.20×10^{-4} (1.60×10^{-4})	---	D	86
		ESP	1.60×10^{-5} (8.00×10^{-6})	---	D	86
		Scrubber	3.50×10^{-4} (1.75×10^{-4})	---	D	86
		Multiple Cyclone without Flyash Reinjection	3.20×10^{-4} (1.60×10^{-4})	---	D	86
1-02-009-06	Wood Waste-fired Boiler (Wood-fired, <50,000 lb steam)	Multiple Cyclone without Flyash Reinjection	3.10×10^{-4} (1.55×10^{-4})	---	D	86
		ESP	1.10×10^{-3} (5.50×10^{-4})	---	D	86
		Scrubber	1.14×10^{-5} lb/MMBtu[b] (4.91×10^{-15} kg/Joule)	---	U	93

[a] Emission factors are expressed in lb (kg) of pollutant emitted per ton (Mg) of wood waste combusted, except as noted. Emission factors are based on wet, as-fired wood waste with average properties of 50 percent moisture and 4,500 Btu/lb higher heating value.
[b] Emission factors are expressed in lb (kg) of pollutant emitted per MMBtu (Joule) of heat input.

"---" means data are not available.
ESP = Electrostatic Precipitator.

TABLE 5-5. LEAD EMISSION FACTORS FOR WOOD WASTE-FIRED COMMERCIAL/INSTITUTIONAL BOILERS

SCC Number	Emission Source	Control Device	Average Emission Factor in lb/ton (kg/Mg)[a]	Emission Factor Range in lb/ton (kg/Mg)[a]	Emission Factor Rating
1-03-009-01	Wood/Bark-fired Boiler (Bark-fired)	None	2.90×10^{-3} (1.45×10^{-3})	---	D
1-03-009-02	Wood/Bark-fired Boiler (Wood/Bark-fired)	Multiple Cyclone with Flyash Reinjection	3.20×10^{-4} (1.60×10^{-4})	---	D
		Scrubber	3.50×10^{-4} (1.75×10^{-4})	---	D
		ESP	1.60×10^{-5} (8.00×10^{-6})	---	D
		Multiple Cyclone without Flyash Reinjection	3.20×10^{-4} (1.60×10^{-4})	---	D
1-03-009-03	Wood/Bark-fired Boiler (Wood-fired)	Multiple Cyclone without Flyash Reinjection	3.10×10^{-4} (1.55×10^{-4})	---	D
		ESP	1.10×10^{-3} (5.50×10^{-4})	---	D

Source: Reference 86

[a] Emission factors are expressed in lb (kg) of pollutant emitted per ton (Mg) of wood waste combusted. Emission factors are based on wet, as-fired wood waste with 50 percent moisture and a higher heating value of 4,500 Btu/lb.

"---" means data are not available.

ESP = Electrostatic Precipitator.

The average emission factors for utility wood waste-fired boilers are presented in Table 5-3. The emission factors represent a range of control configurations and wood waste compositions.[86]

Average emission factors for industrial wood waste-fired boilers are presented in Table 5-4. Several of the emission factors are based on a comprehensive toxic air emission testing program in California. The study, conducted by the Timber Association of California (TAC), tested boiler types with capacities greater than 50,000 lb (22,680 kg) of steam per hour, including fuel cell, dutch oven, stoker, air injection, and fluidized bed combustors. The summarized results of the study were used to obtain the average lead emission factors. The emission factors represent a range of boiler designs and capacities, control configurations, and wood waste compositions. The range of control devices represented in the sample set included multiple cyclones, ESPs, and wet scrubbers. Sampling was conducted using CARB Method 431, which captures particulate lead.[89,90,91]

Wood waste-fired commercial/institutional boilers average emission factors are presented in Table 5-5. These emission factors represent a range of control configurations and wood waste compositions.[86] Many of these same emission factors can be found in the utility, commercial/institutional, and industrial wood waste-fired tables. This duplication is expected because the same types of boilers and waste composition are found in all three industry categories.

Natural Gas Combustion

There were few data available for deriving lead emission factors for natural gas-fired utility boilers. Based on the limited data available, it is unclear whether there are significant lead emissions from these boilers. Tables 5-6 and 5-7 present lead emission factors for natural gas fired boilers.

TABLE 5-6. LEAD EMISSION FACTORS FOR NATURAL GAS - FIRED UTILITY BOILERS FROM AP-42

SCC Number	Emission Source	Control Device	Average Emission Factor in lb/ton (kg/Mg)[a]	Emission Factor Range in lb/ton (kg/Mg)[a]	Emission Factor Rating	Reference
1-01-006-04	Natural Gas Boiler	[b]	2.71×10^{-4}	---	E	94

[a] To convert from lb/million ft^3 to Kg/million m^3 multiply by 16.0.
[b] Data for boilers controlled with overfire air and flue gas recirculation.

TABLE 5-7. LEAD EMISSION FACTORS FOR NATURAL GAS - FIRED BOILERS FROM UTILITY STUDY

Emission Source	Control Device	Median Factor (lb/trillion BTU	Emission Factor Rating	Reference
Gas Fired Units	None	0.37	U	95

Coal Combustion

Lead emission factors for coal-fired utility boilers are presented in Tables 5-8 and 5-9. The tables include composite emission factors for anthracite, bituminous pulverized wet-bottom, and bituminous pulverized dry-bottom boilers. The emission factors include particulate lead.[55]

Lead emission factors for coal-fired industrial and commercial/institutional boilers are listed in Tables 5-10 and 5-11, respectively. Composite emission factors for two industrial boiler design categories, pulverized bituminous dry-bottom boilers and bituminous stokers, are presented. Control configurations include uncontrolled and multicyclone controlled. Both sets of lead emission factors represent particulate lead emissions.[76,98,99]

AP-42, Section 1.1 also includes an equation for bituminous coal, subbituminous coal and lignite combustion. This equation can be used for both controlled and uncontrolled boilers. The equation is also applicable to all typical firing configurations of utility, industrial and commercial/industrial boilers. The equation for lead is as follows:

$$\text{Lead emissions (lb/}10^{12}\text{ BTU)} = 3.4\left[\left(\frac{C}{A} * PM\right)^{0.8}\right]$$

where:
C = concentration of metal in the coal, parts per million by weight (ppmwt)
A = weight fraction of ash in the coal. For example, 10% ash is 0.1 ash fraction
PM = site-specific emission factor for total particulate matter, lb/10^6 Btu.

The factors produced by the equation should be applied to heat input.[97]

TABLE 5-8. LEAD EMISSION FACTORS FOR COAL-FIRED UTILITY BOILERS

SCC Number	Emission Source	Control Device	Average Emission Factor in lb/ton (kg/Mg)[a]	Emission Factor Range in lb/ton (kg/Mg)[a]	Emission Factor Rating	Reference
1-01-001-02	Anthracite Coal Traveling Grate Overfeed Stoker	None	8.90×10^{-3} (4.45×10^{-3})	---	E	96
1-01-002-01	Bituminous Coal: Pulverized: Wet Bottom	None	5.07×10^{-4} lb/MMBtu[b] $(2.18 \times 10^{-13}$ kg/Joule)	---	E	97
1-01-002-02	Bituminous Coal: Pulverized: Dry Bottom	None	5.07×10^{-4} lb/MMBtu[b] $(2.18 \times 10^{-13}$ kg/Joule)	---	E	97
		ESP, FF or venturi scrubber	4.20×10^{-4} lb/ton[c] $(2.10 \times 10^{-4}$ kg/Mg)	---	A	97
1-01-002-03	Bituminous Coal: Cyclone Furnace	None	5.07×10^{-4} lb/MMBtu[b] $(2.18 \times 10^{-13}$ kg/Joule)	---	E	97
		ESP, FF or venturi scrubber	4.20×10^{-4} lb/ton[c] $(2.10 \times 10^{-4}$ kg/Mg)	---	A	97
1-01-002-04	Bituminous Coal: Spreader Stoker	None	5.07×10^{-4} lb/MMBtu[b] $(2.18 \times 10^{-13}$ kg/Joule)	---	E	97
1-01-002-05	Bituminous Coal: Traveling Grate (Overfeed) Stoker	None	5.07×10^{-4} lb/MMBtu[b] $(2.18 \times 10^{-13}$ kg/Joule)	---	E	97
1-01-002-21	Subbituminous Coal: Pulverized: Wet Bottom	None	5.07×10^{-4} lb/MMBtu[b] $(2.18 \times 10^{-13}$ kg/Joule)	---	E	97

TABLE 5-8. LEAD EMISSION FACTORS FOR COAL-FIRED UTILITY BOILERS (CONTINUED)

SCC Number	Emission Source	Control Device	Average Emission Factor in lb/ton (kg/Mg)[a]	Emission Factor Range in lb/ton (kg/Mg)[a]	Emission Factor Rating	Reference
1-01-002-22	Subbituminous Coal: Pulverized: Dry Bottom	None	5.07×10^{-4} lb/MMBtu[b] (2.18×10^{-13} kg/Joule)	---	E	97
		ESP, FF or venturi scrubber	4.20×10^{-4} lb/ton[c] (2.10×10^{-4} kg/Mg)	---	A	97
1-01-002-23	Subbituminous Coal: Cyclone Furnace	None	5.07×10^{-4} lb/MMBtu[b] (2.18×10^{-13} kg/Joule)	---	E	97
		ESP, FF or venturi scrubber	4.20×10^{-4} lb/ton[c] (2.10×10^{-4} kg/Mg)	---	A	97
1-01-002-24	Subbituminous Coal: Spreader Stoker	None	5.07×10^{-4} lb/MMBtu[b] (2.18×10^{-13} kg/Joule)	---	E	97
1-01-002-25	Subbituminous Coal: Traveling Grate (Overfeed) Stoker	None	5.07×10^{-4} lb/MMBtu[b] (2.18×10^{-13} kg/Joule)	---	E	97

[a] Emission factors are expressed in lb (kg) of pollutant emitted per ton (Mg) of coal combusted, except as noted.
[b] Emission factors are expressed in lb (kg) of pollutant emitted per MMBtu (Joule) of heat input.
[c] Emission factor should be applied to coal feed, as fired.

"---" means data are not available.

TABLE 5-9. LEAD EMISSION FACTORS FOR COAL-FIRED BOILERS FROM UTILITY STUDY

Emission Source	Control Device	Median Factor (lb/trillion BTU)	Emission Factor Rating	Reference
Coal Fired Units	PM Control	4.8	U	95
	PM/SO$_2$ Control	5.8	U	95

TABLE 5-10. LEAD EMISSION FACTORS FOR COAL-FIRED INDUSTRIAL BOILERS

SCC Number	Emission Source	Control Device	Average Emission Factor in lb/ton (kg/Mg)[a]	Emission Factor Range in lb/ton (kg/Mg)[a]	Emission Factor Rating	Reference
1-02-001-04	Anthracite Coal Traveling Grate (Overfeed) Stoker	None	8.90×10^{-3} (4.45×10^{-3})	---	E	96
1-02-002-01	Bituminous Coal Pulverized: Wet Bottom	None	5.07×10^{-4} lb/MMBtu[b] (2.18×10^{-13} kg/Joule)	---	E	97
1-02-002-02	Bituminous Coal Pulverized Coal: Dry Bottom	None	5.07×10^{-4} lb/MMBtu[b] (2.18×10^{-13} kg/Joule)	---	E	97
		ESP, FF, or venturi scrubber	4.20×10^{-4} lb/ton[c] (2.10×10^{-4} kg/Mg)	---	A	97
1-02-002-03	Bituminous Coal Cyclone Furnace	None	5.07×10^{-4} lb/MMBtu[b] (2.18×10^{-13} kg/Joule)	---	E	97
		ESP, FF, or venturi scrubber	4.20×10^{-4} lb/ton[c] (2.10×10^{-4} kg/Mg)	---	A	97
1-02-002-04	Bituminous Coal Spreader Stoker	None	5.07×10^{-4} lb/MMBtu[b] (2.18×10^{-13} kg/Joule)	---	E	97
1-02-002-05	Bituminous Coal Overfeed Stoker	None	5.07×10^{-4} lb/MMBtu[b] (2.18×10^{-13} kg/Joule)	---	E	97
1-02-002-06	Bituminous Coal Underfeed Stoker	None	2.24×10^{-1} (1.12×10^{-1})	---	U	76
1-02-002-13	Bituminous Coal Wet Slurry	None	9.89×10^{-3} (4.95×10^{-3})	---	U	93
1-01-002-21	Subbituminous Coal: Pulverized: Wet Bottom	None	5.07×10^{-4} lb/MMBtu[b] (2.18×10^{-13} kg/Joule)	---	E	97

TABLE 5-10. LEAD EMISSION FACTORS FOR COAL-FIRED INDUSTRIAL BOILERS (CONTINUED)

SCC Number	Emission Source	Control Device	Average Emission Factor in lb/ton (kg/Mg)[a]	Emission Factor Range in lb/ton (kg/Mg)[a]	Emission Factor Rating	Reference
1-01-002-22	Subbituminous Coal: Pulverized: Dry Bottom	None	5.07×10^{-4} lb/MMBtu[b] (2.18×10^{-13} kg/Joule)	---	E	97
		ESP, FF, or venturi scrubber	4.20×10^{-4} lb/ton[c] (2.10×10^{-4} kg/Mg)	---	A	97
1-01-002-23	Subbituminous Coal: Cyclone Furnace	None	5.07×10^{-4} lb/MMBtu[b] (2.18×10^{-13} kg/Joule)	---	E	97
		ESP, FF, or venturi scrubber	4.20×10^{-4} lb/ton[c] (2.10×10^{-4} kg/Mg)	---	A	97
1-01-002-24	Subbituminous Coal: Spreader Stoker	None	5.07×10^{-4} lb/MMBtu[b] (2.18×10^{-13} kg/Joule)	---	E	97
1-01-002-25	Subbituminous Coal: Traveling Grate (Overfeed) Stoker	None	5.07×10^{-4} lb/MMBtu[b] (2.18×10^{-13} kg/Joule)	---	E	97

[a] Emission factors are expressed in lb (kg) of pollutant emitted per ton (Mg) of coal combusted, except as noted.
[b] Emission factors are expressed in lb (kg) of pollutant emitted per MMBtu (Joule) of heat input.
[c] Emission factor should be applied to coal feed, as fired.
"---" means data are not available.

TABLE 5-11. LEAD EMISSION FACTORS FOR COAL-FIRED COMMERCIAL/INSTITUTIONAL BOILERS

SCC Number	Emission Source	Control Device	Average Emission Factor in lb/ton (kg/Mg)[a]	Emission Factor Range in lb/ton (kg/Mg)[a]	Emission Factor Rating	Reference
1-03-001-02	Anthracite Coal Traveling Grate (Overfeed) Stoker	None	8.90×10^{-3} (4.45×10^{-3})	---	E	96
1-03-002-08	Bituminous Coal Underfeed Stoker	Multiple Cyclone without Flyash Reinjection	1.21×10^{-3} (6.05×10^{-4})	---	U	98
1-03-002-03	Bituminous Coal Cyclone Furnace	None	5.07×10^{-4} lb/MMBtu[b] (2.18×10^{-13} kg/Joule)	---	E	97
		ESP, FF, or venturi scrubber	4.20×10^{-4} lb/ton (2.10×10^{-4} kg/Mg)[c]	---	A	97
1-03-002-05	Bituminous Coal Pulverized: Wet Bottom	None	5.07×10^{-4} lb/MMBtu[b] (2.18×10^{-13} kg/Joule)	---	E	97
1-03-002-06	Bituminous Coal Pulverized Coal: Dry Bottom	None	5.07×10^{-4} lb/MMBtu[b] (2.18×10^{-13} kg/Joule)	---	E	97
		ESP, FF, or venturi scrubber	4.20×10^{-4} lb/ton (2.10×10^{-4} kg/Mg)[c]	---	A	97
1-03-002-07	Bituminous Coal Overfeed Stoker	None	5.07×10^{-4} lb/MMBtu[b] (2.18×10^{-13} kg/Joule)	---	E	97
1-03-002-09	Bituminous Coal Spreader Stoker	None	5.07×10^{-4} lb/MMBtu[b] (2.18×10^{-13} kg/Joule)	---	E	97
1-03-002-21	Subbituminous Coal: Pulverized: Wet Bottom	None	5.07×10^{-4} lb/MMBtu[b] (2.18×10^{-13} kg/Joule)	---	E	97

TABLE 5-11. LEAD EMISSION FACTORS FOR COAL-FIRED COMMERCIAL/INSTITUTIONAL BOILERS (CONTINUED)

SCC Number	Emission Source	Control Device	Average Emission Factor in lb/ton (kg/Mg)[a]	Emission Factor Range in lb/ton (kg/Mg)[a]	Emission Factor Rating	Reference
1-03-002-22	Subbituminous Coal: Pulverized: Dry Bottom	None	5.07×10^{-4} lb/MMBtu[b] (2.18×10^{-13} kg/Joule)	---	E	97
		ESP, FF, or venturi scrubber	4.20×10^{-4} lb/ton (2.10×10^{-4} kg/Mg)[c]	---	A	97
1-03-002-23	Subbituminous Coal: Cyclone Furnace	None	5.07×10^{-4} lb/MMBtu[b] (2.18×10^{-13} kg/Joule)	---	E	97
		ESP, FF, or venturi scrubber	4.20×10^{-4} lb/ton (2.10×10^{-4} kg/Mg)[c]	---	A	97
1-03-002-24	Subbituminous Coal: Spreader Stoker	None	5.07×10^{-4} lb/MMBtu[b] (2.18×10^{-13} kg/Joule)	---	E	97
1-03-002-25	Subbituminous Coal: Traveling Grate (Overfeed) Stoker	None	5.07×10^{-4} lb/MMBtu[b] (2.18×10^{-13} kg/Joule)	---	E	97

[a] Emission factors are expressed in lb (kg) of pollutant emitted per ton (Mg) of coal combusted, except as noted.
[b] Emission factors are expressed in lb (kg) of pollutant emitted per MMBtu/Joule of heat input.
[c] Emission factor should be applied to coal feed, as fired.
"---" means data are not available.

Oil Combustion

Lead emission factors for oil-fired utility boilers are presented in Tables 5-12 and 5-13. Lead emission factors for oil-fired industrial and commercial/institutional boilers are presented in Tables 5-14 through 5-17.

Emission factors for specific utility boiler and control device configurations are also listed in Table 5-12, as are emission factors for residual oil and distillate oil combustion.

Lead emission factors for oil-fired industrial boilers are presented in Table 5-14. The data used in factor development came from the testing of two uncontrolled units. Testing was conducted using CARB Method 436. The emission factors represent particulate lead.[100]

A lead emission factor for oil-fired commercial/institutional boilers is provided in Table 5-15. The average emission factor is based on a boiler with a rated capacity of less than 10 MMBtu/hr (2.9 MW).[101]

Lead emission factors for industrial and commercial/institutional waste oil combustion are shown in Tables 5-16 and 5-17, respectively. Emission factors are available for two basic types of uncontrolled space heaters: a vaporizing pot-type burner and an air atomizing burner. The use of both blended and unblended fuels is reflected in these factors.

Solid Waste Combustion

Lead emission factors for solid-waste fired utility boilers are presented in Table 5-18.

Miscellaneous Combustion

Lead emission factors for industrial boilers firing other fuel types (i.e., solid waste refuse-derived fuel) are presented in Table 5-19.

TABLE 5-12. LEAD EMISSION FACTORS FOR OIL-FIRED UTILITY BOILERS

SCC Number	Emission Source	Control Device	Average Emission Factor in lb/MMBtu (kg/Joule)[a]	Emission Factor Range in lb/MMBtu (kg/Joule)[a]	Emission Factor Rating	Reference
1-01-004-01	Residual Oil-fired Boiler: No. 6 Oil, Normal Firing	None	1.0×10^{-5} (4.33×10^{-15})	---	C	102
		Flue Gas Recirculation	2.17×10^{-5} (9.35×10^{-15})	1.26×10^{-5} - 2.83×10^{-5} 5.43×10^{-15} - 1.22×10^{-14})	U	103
1-01-004-04	Residual Oil-fired Boiler: No. 6 Oil, Tangential Firing	None	1.0×10^{-5} (4.33×10^{-15})	---	C	102
1-01-004-05	Residual Oil-fired Boiler: No. 5 Oil, Normal Firing	None	1.60×10^{-5} (6.89×10^{-15})	---	U	104
1-01-005-01	Distillate Oil Grades 1 and 2 Oil	None	8.90×10^{-6} (3.84×10^{-15})	---	E	102

[a] Emission factors are expressed in lb (kg) of pollutant emitted per MMBtu (Joule) of heat input.

"---" means data are not available.

TABLE 5-13 LEAD EMISSION FACTORS FOR OIL-FIRED UTILITY BOILER FROM UTILITY STUDY

Emission Source	Control Device	Median Factor (lb/trillion BTU)	Emission Factor Rating	Reference
Oil-Fired Units	PM Control	2.6	U	95
	PM/SO$_2$ Control	9.0	U	95

5-40

TABLE 5-14. LEAD EMISSION FACTORS FOR OIL-FIRED INDUSTRIAL BOILERS

SCC Number	Emission Source	Control Device	Average Emission Factor in lb/MMBtu (kg/Joule)[a]	Emission Factor Range in lb/MMBtu (kg/Joule)[a]	Emission Factor Rating
1-02-004-01	Residual Oil Grade 6 Oil	None	$1.00 \times 10^{-5(b)}$ (4.33×10^{-15})		C
1-02-005-01	Distillate Oil Grades 1 and 2 Oil	None	8.90×10^{-6} (3.84×10^{-15})	---	E

Source: Reference 102

[a] Emission factors are expressed in lb (kg) of pollutant emitted per MMBtu (Joule) of heat input.
[b] Emission factor is in lb x 10^3 gal, to convert to kb/10^3 L, multiply by 0.12.
"---" means data are not available.

TABLE 5-15. LEAD EMISSION FACTORS FOR OIL-FIRED COMMERCIAL/INSTITUTIONAL BOILERS

SCC Number	Emission Source	Control Device	Average Emission Factor in lb/MMBtu (kg/Joule)[a]	Emission Factor Range in lb/MMBtu (kg/Joule)[a]	Emission Factor Rating
1-03-004-01	Residual Oil Grade 6 Oil	None	$1.00 \times 10^{-5(b)}$ (4.33×10^{-15})	---	C
1-03-005-01	Distillate Oil Grades 1 and 2 Oil	None	8.90×10^{-6} (3.84×10^{-15})	---	E

Source: Reference 102

[a] Emission factors are expressed in lb (kg) of pollutant emitted per MMBtu (Joule) of heat input.
[b] Emission factor is in lb/10^3 gal, to convert to kg/10^3 L, multiply by 0.12.
"---" means data are not available.

TABLE 5-16. LEAD EMISSION FACTORS FOR WASTE OIL-FIRED INDUSTRIAL BOILERS

SCC Number	Emission Source	Control Device	Average Emission Factor in lb/1000 gal (kg/kL)[a]	Emission Factor Range in lb/1000 gal (kg/kL)[a]	Emission Factor Rating	Reference
1-02-013-02	Waste Oil	None	1.68 (2.01×10^{-1})	---	U	105
1-05-001-13	Waste Oil Air Atomized Burner	None	50L[b] (6.0L)	---	D	106

[a] Emission factors are expressed in lb (kg) of pollutant emitted per 1000 gallons (kL) of oil combusted.
[b] L=weight % lead in fuel. Multiply numeric value by L to obtain emission factor.
"---" means data are not available.

TABLE 5-17. LEAD EMISSION FACTORS FOR WASTE OIL-FIRED COMMERCIAL/INSTITUTIONAL BOILERS

SCC Number	Emission Source	Control Device	Average Emission Factor in lb/1000 gal (kg/kL)[a]	Emission Factor Range in lb/1000 gal (kg/kL)[a]	Emission Factor Rating	Reference
1-01-013-02	Waste Oil	None	1.68 (2.01x10^{-1})	---	U	23
1-05-002-13	Waste Oil Air Atomized Burner	None	50L[b] (6.0L)	---	D	106

[a] Emission factors are expressed in lb (kg) of pollutant emitted per 1000 gallons (kL) of oil combusted.
[b] L=weight % lead in fuel. Multiply numeric value by L to obtain emission factor.

"---" means data are not available.

TABLE 5-18. LEAD EMISSION FACTORS FOR SOLID WASTE-FIRED UTILITY BOILERS

SCC Number	Emission Source	Control Device	Average Emission Factor in lb/ton (kg/Mg)[a]	Emission Factor Range in lb/ton (kg/Mg)[a]	Emission Factor Rating	Reference
1-01-012-01	Solid Waste	None	2.65×10^{-1} (1.33×10^{-1})	2.00×10^{-1} - 3.40×10^{-1} $(1.00 \times 10^{-1}$ - $1.70 \times 10^{-1})$	U	108
		ESP	1.24×10^{-4} lb/MMBtu $(5.34 \times 10^{-14}$ kg/Joule$)^b$	8.15×10^{-5} - 2.04×10^{-4} lb/MMBtu $(1.51 \times 10^{-14}$ - 3.78×10^{-14} kg/Joule$)^b$	C	108
		Spray Dryer/Absorber/ESP	$<2.66 \times 10^{-4}$ $(<1.33 \times 10^{-4})$	$<1.30 \times 10^{-4}$ - 3.66×10^{-4} $(<6.50 \times 10^{-5}$ - $1.83 \times 10^{-4})$	U	109

[a] Emission factors are expressed in lb (kg) of pollutant emitted per ton (Mg) of waste combusted, except as noted.
[b] Emission factors are expressed in lb (kg) of pollutant emitted per MMBtu (Joule) of heat input.

"---" means data are not available.

ESP = Electrostatic Precipitator.

TABLE 5-19. LEAD EMISSION FACTORS FOR MISCELLANEOUS INDUSTRIAL BOILERS

SCC Number	Emission Source	Control Device	Average Emission Factor in lb/ton (kg/Mg)[a]	Emission Factor Range in lb/ton (kg/Mg)[a]	Emission Factor Rating
1-02-012-02	Solid Waste Refuse-derived Fuel	None	1.30×10^{-1} (6.50×10^{-2})	---	U

Source: Reference 23

[a] Emission factors are expressed in lb (kg) of pollutant emitted per ton (Mg) of waste combusted.

"---" means data are not available.

5.2   STATIONARY INTERNAL COMBUSTION SOURCES

5.2.1   Source Description

        Internal combustion sources for electricity generation and industrial application are grouped into two types: gas turbines and reciprocating engines.

        Stationary gas turbines are applied in electric power generators, in gas pipeline pump and compressor drives, and various process industries. Gas turbines greater than 3 MW are used in electricity generation for continuous, peaking, or standby power. The primary fuels used are natural gas and distillate (No. 2) fuel oil.[107]

        Reciprocating internal combustion engines may be classified as spark ignition and compression ignition. Spark ignition engines are fueled by volatile liquids such as gasoline, while compression ignition engines use liquid fuels of low volatility, such as kerosene and distillate oil (diesel fuel).[110]

        In compression ignition engines, combustion air is compression-heated in the cylinder and diesel fuel oil is then injected into this hot air. Ignition is spontaneous because the air is above the autoignition temperature of the fuel. Spark ignition engines initiate combustion with an electrical discharge. Usually, fuel is mixed with air in a carburetor (for gasoline) or at the intake valve (for natural gas), but fuel can also be injected directly into the cylinder.[111]

        The rated power of gasoline and diesel internal combustion engines covers a substantial range: up to 250 hp (186 kW) for gasoline engines and greater than 600 hp (447 kW) for diesel engines. The primary domestic use of large stationary diesel engines (greater than 600 hp) is in oil and gas exploration and production. These engines supply mechanical power to operate drilling (rotary table), mud pumping, and hoisting equipment and may also operate pumps or auxiliary power generators.[112] Stationary natural gas-fired spark ignition engines of over 5,000 hp and natural gas-fired turbines of over 10,000 hp exist.

5.2.2   Emissions

          Air emissions from the flue gas stack are the only emissions from electricity generation, industrial turbines, and reciprocating engines. Turbines firing distillate or residual oil may emit trace metals carried over from the metals content of the fuel.

          An emissions assessment study of internal combustion sources developed in 1979 presents a lead emission factor for distillate oil-fired gas turbines of 5.8×10^{-5} lb/MMBtu (25 picogram/joule [pg/J]).[110] More recent test results for distillate oil-fired gas turbines indicate an average lead emission factor of 2.9×10^{-5} lb/MMBtu.[113] The data used to develop these emission factors are limited and may not be representative of a specific source or population of sources. However, the emission factors provide order-of-magnitude levels of lead emissions for turbines fired with distillate oil. Emissions of trace elements, including lead, from the gas-fired gas turbine tested during the 1979 study were insignificant.[110]

          If the fuel analysis is known, the metals content of the fuel should be used for flue gas emission factors, assuming all metals pass through the turbine.[107] The average fuel analysis result can be used to calculate emissions based on fuel usage or stack exhaust flow measurements. Potential emissions based on the trace element content of distillate oils have been calculated and compared with measured stack emissions.[110] In almost all cases, the potential emissions were higher than the measured emissions. Limited lead emissions and lead emission factors were available for the other emission sources indicated in this section.

5.3   MUNICIPAL WASTE INCINERATION

5.3.1   Source Location

          As of January 1992, there were 160 municipal waste combustor (MWC) plants operating in the United States with capacities greater than 40 tons/day (36 Mg/day), with a total capacity of approximately 110,000 tons/day (100,000 Mg/day) of municipal solid waste (MSW). It is projected that by 1997, total MWC capacity will approach 165,000 tons/day

(150,000 Mg/day), which represents approximately 28 percent of the estimated total amount of MSW that will be generated in the United States by the year 2000.[114] Table 5-20 lists the geographical distribution of MWC units and statewide capacities.[115]

5.3.2   Process Description

        MWCs burn garbage and other nonhazardous solid waste, commonly called MSW. Three main types of combustors are used to combust MSW: mass burn, refuse-derived fuel-fired (RDF), and modular. Each type is discussed in this section.

        Mass Burn Combustors

        In mass burn units, MSW is combusted without any preprocessing other than removal of items too large to go through the feed system. In a typical mass burn combustor, refuse is placed on a grate that moves through the combustor. Combustion air in excess of stoichiometric amounts is supplied both below (underfire air) and above (overfire air) the grate. Mass burn combustors are erected at the site (as opposed to being prefabricated) and range in size from 50 to 1,000 tons/day (46 to 900 Mg/day) of MSW throughput per unit. Mass burn combustors can be divided into mass burn/waterwall (MB/WW), mass burn/rotary waterwall (MB/RC), and mass burn/refractory wall (MB/REF) designs.

        The walls of a MB/WW combustor are constructed of metal tubes that contain pressurized water and recover radiant heat for production of steam and/or electricity. A typical MB/WW combustor is shown in Figure 5-5. With the MB/RC combustor, a rotary combustion chamber sits at a slight angle and rotates at about 10 revolutions per hour, causing the waste to advance and tumble as it burns. The combustion cylinder consists of alternating water tubes and perforated steel plates. Figure 5-6 illustrates a simplified process flow diagram for a MB/RC. MB/REF designs are older and typically do not include any heat recovery. One type of MB/REF combustor is shown in Figure 5-7.

TABLE 5-20. SUMMARY OF GEOGRAPHICAL DISTRIBUTION OF MWC FACILITIES

State	Number of MWC Facilities	State MWC Capacity in tons/day (Mg/day)	Percentage of Total U.S. MWC Capacity
Alabama	2	990 (900)	1
Alaska	2	170 (150)	<1
Arkansas	5	380 (350)	<1
California	3	2,560 (2,330)	2
Connecticut	9	6,660 (6,050)	6
Delaware	1	600 (550)	<1
District of Columbia	1	1,000 (910)	1
Florida	14	17,350 (15,770)	16
Georgia	1	500 (450)	<1
Hawaii	1	2,760 (2,510)	2
Idaho	1	50 (45)	<1
Illinois	1	1,600 (1,450)	1
Indiana	1	2,360 (2,150)	2
Iowa	1	200 (180)	<1
Maine	4	1,870 (1,700)	2

TABLE 5-20. SUMMARY OF GEOGRAPHICAL DISTRIBUTION OF MWC FACILITIES
(CONTINUED)

State	Number of MWC Facilities	State MWC Capacity in tons/day (Mg/day)	Percentage of Total U.S. MWC Capacity
Maryland	3	3,810 (3,460)	3
Massachusetts	10	10,340 (9,400)	9
Michigan	5	4,820 (4,380)	4
Minnesota	13	5,330 (4,850)	5
Mississippi	1	150 (140)	<1
Missouri	1	78 (71)	<1
Montana	1	72 (65)	<1
New Hampshire	4	860 (780)	1
New Jersey	6	5,820 (5,290)	5
New York	15	12,510 (11,370)	11
North Carolina	4	780 (710)	1
Ohio	4	4,800 (4,360)	4
Oklahoma	2	1,230 (1,120)	1
Oregon	3	810 (740)	1
Pennsylvania	6	7,200 (6,550)	6

TABLE 5-20. SUMMARY OF GEOGRAPHICAL DISTRIBUTION OF MWC FACILITIES (CONTINUED)

State	Number of MWC Facilities	State MWC Capacity in tons/day (Mg/day)	Percentage of Total U.S. MWC Capacity
Puerto Rico	1	1,040 (950)	1
South Carolina	2	840 (760)	1
Tennessee	4	1,480 (1,350)	1
Texas	4	240 (220)	<1
Utah	1	400 (360)	<1
Virginia	9	6,840 (6,220)	6
Washington	5	1,500 (1,360)	1
Wisconsin	9	1,360 (1,240)	1
TOTAL	160	111,400 (101,200)	100

Source: Reference 115
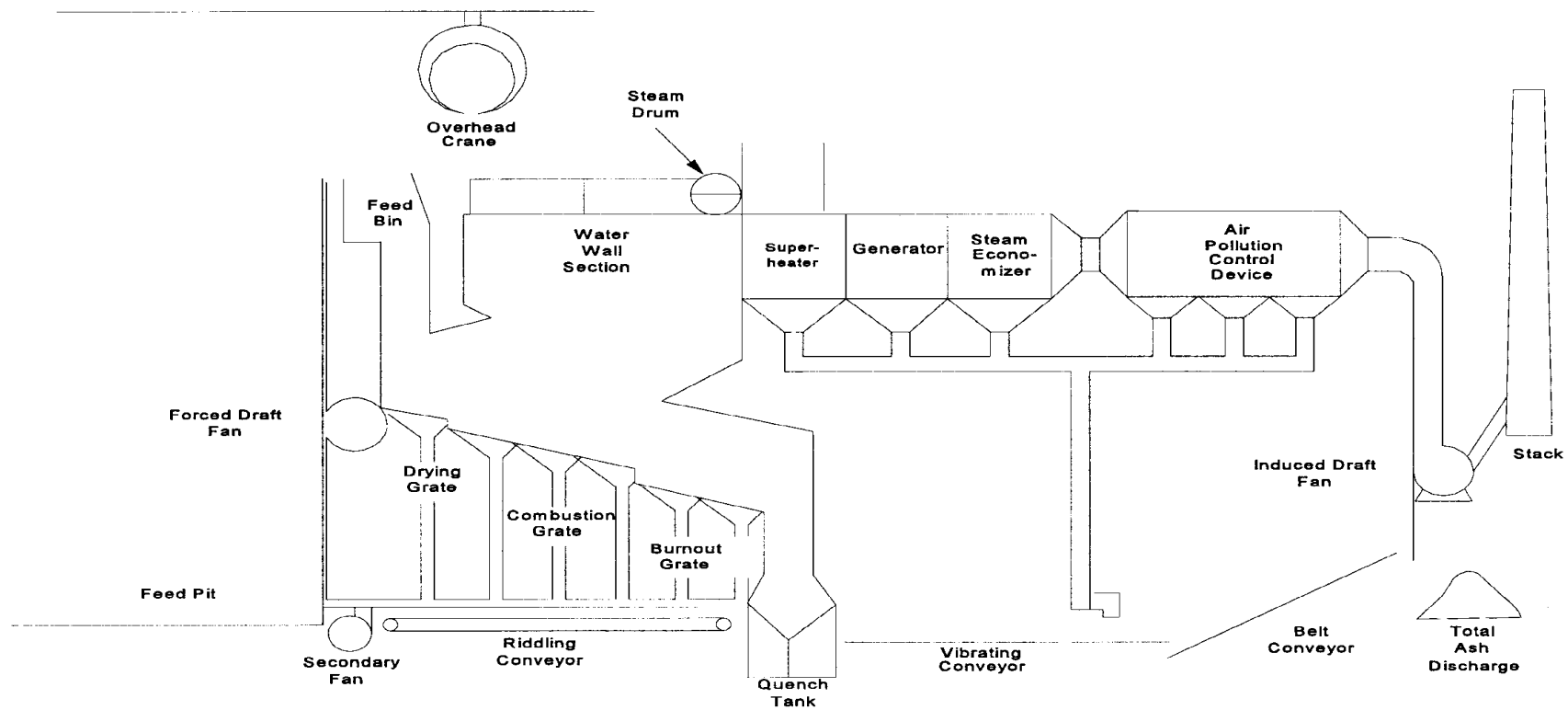
Figure 5-5. Typical Mass Burn Waterwall Combustor
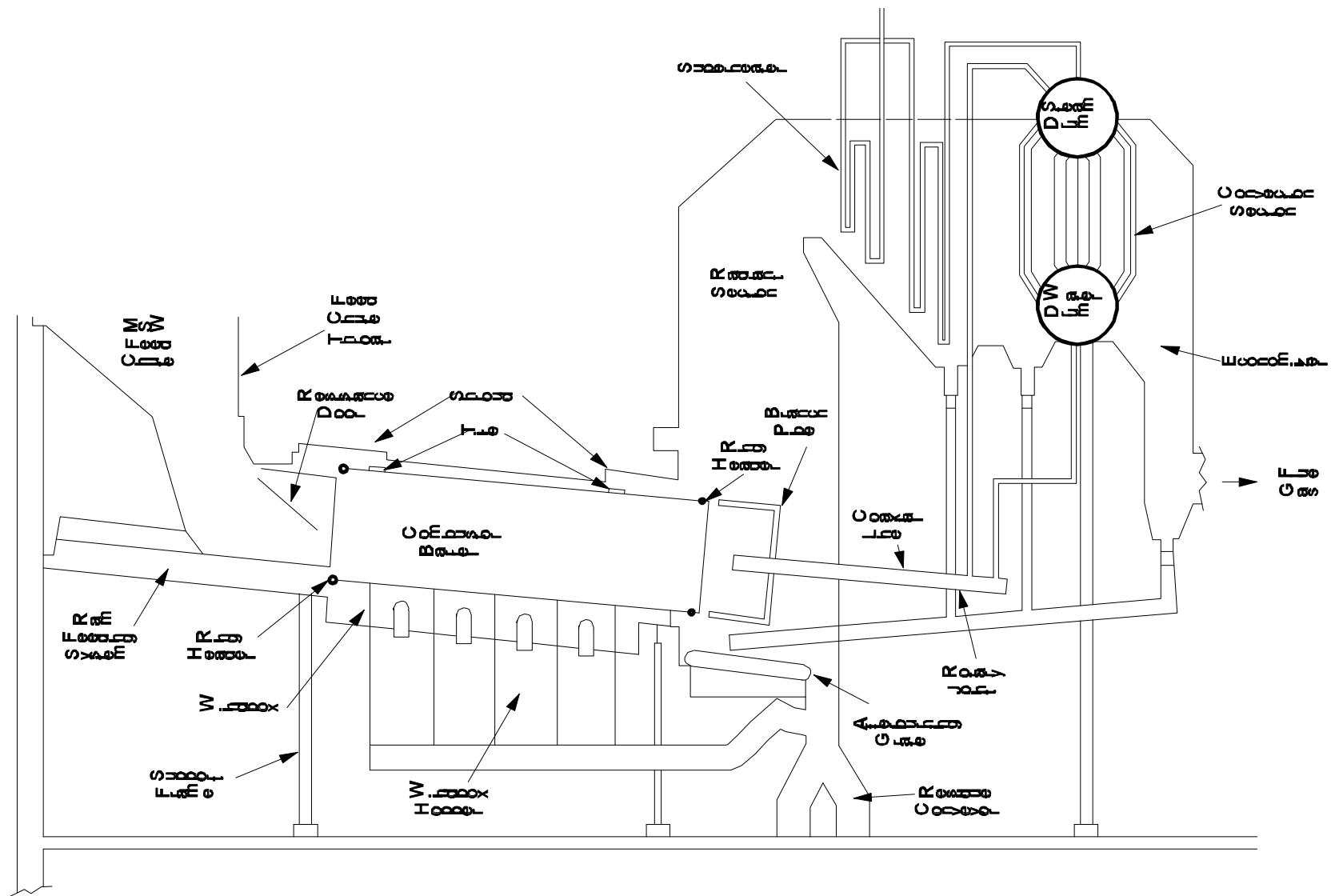
Source: Reference 114.

Figure 5-6. Simplified Process Flow Diagram, Gas Cycle for a Mass Burn/Rotary Waterwall
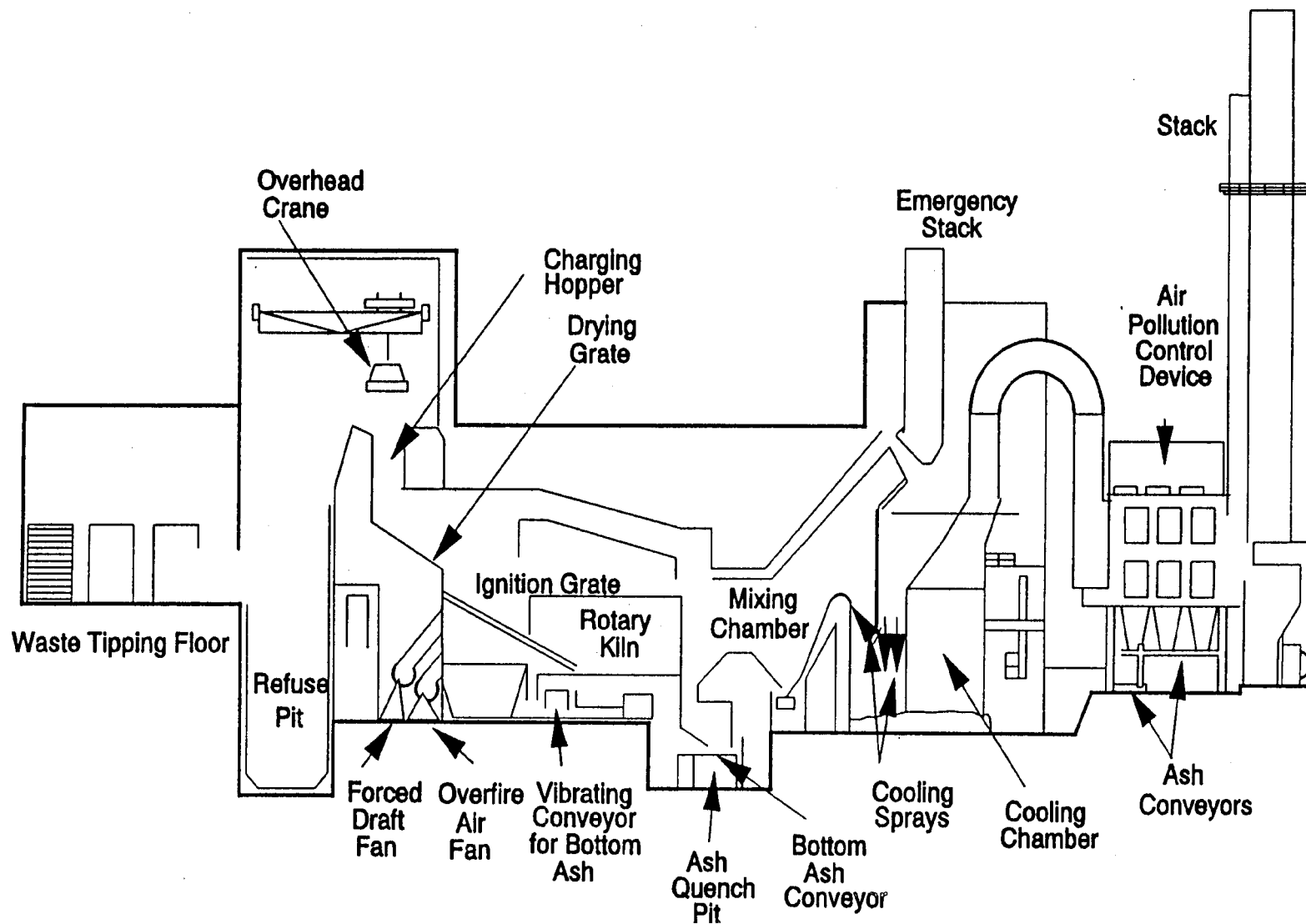Combustor

Source: Reference 114.

Figure 5-7. Mass Burn Refractory-Wall Combustor with Grate/Rotary Kiln

Source: Reference 114.

RDF-Fired Combustors

RDF-fired combustors burn processed waste that varies from shredded waste to finely divided fuel suitable for co-firing with pulverized coal. Combustor sizes range from 320 to 1,400 tons/day (290 to 1,300 Mg/day). There are three major types of RDF-fired combustors: dedicated RDF combustors, which are designed to burn RDF as a primary fuel; coal/RDF co-fired combustors; and fluidized-bed combustors (FBCs), where waste is combusted on a turbulent bed of limestone, sand, silica or aluminum.

A typical RDF-fired combustor is shown in Figure 5-8 . Waste processing usually consists of removing noncombustibles and shredding, which generally raises the heating value and provides a more uniform fuel. The type of RDF used depends on the boiler design. Most boilers designed to burn RDF use spreader stokers and fire fluff RDF in a semi-suspension mode.

Modular Combustors

Modular combustors are similar to mass burn combustors in that they burn waste that has not been pre-processed, but they are typically shop-fabricated and generally range in size from 5 to 140 tons/day (4 to 130 Mg/day) of MSW throughput. One of the most common types of modular combustors is the starved-air or controlled-air type, which incorporates two combustion chambers. A process diagram of a typical modular starved-air (MOD/SA) combustor is presented in Figure 5-9. Air is supplied to the primary chamber at sub-stoichiometric levels. The incomplete combustion products (CO and organic compounds) pass into the secondary combustion chamber, where additional air is added and combustion is completed. Another design is the modular excess air (MOD/EA) combustor, which consists of two chambers, similar to MOD/SA units, but is functionally like the mass burn unit in that it uses excess air in the primary chamber.
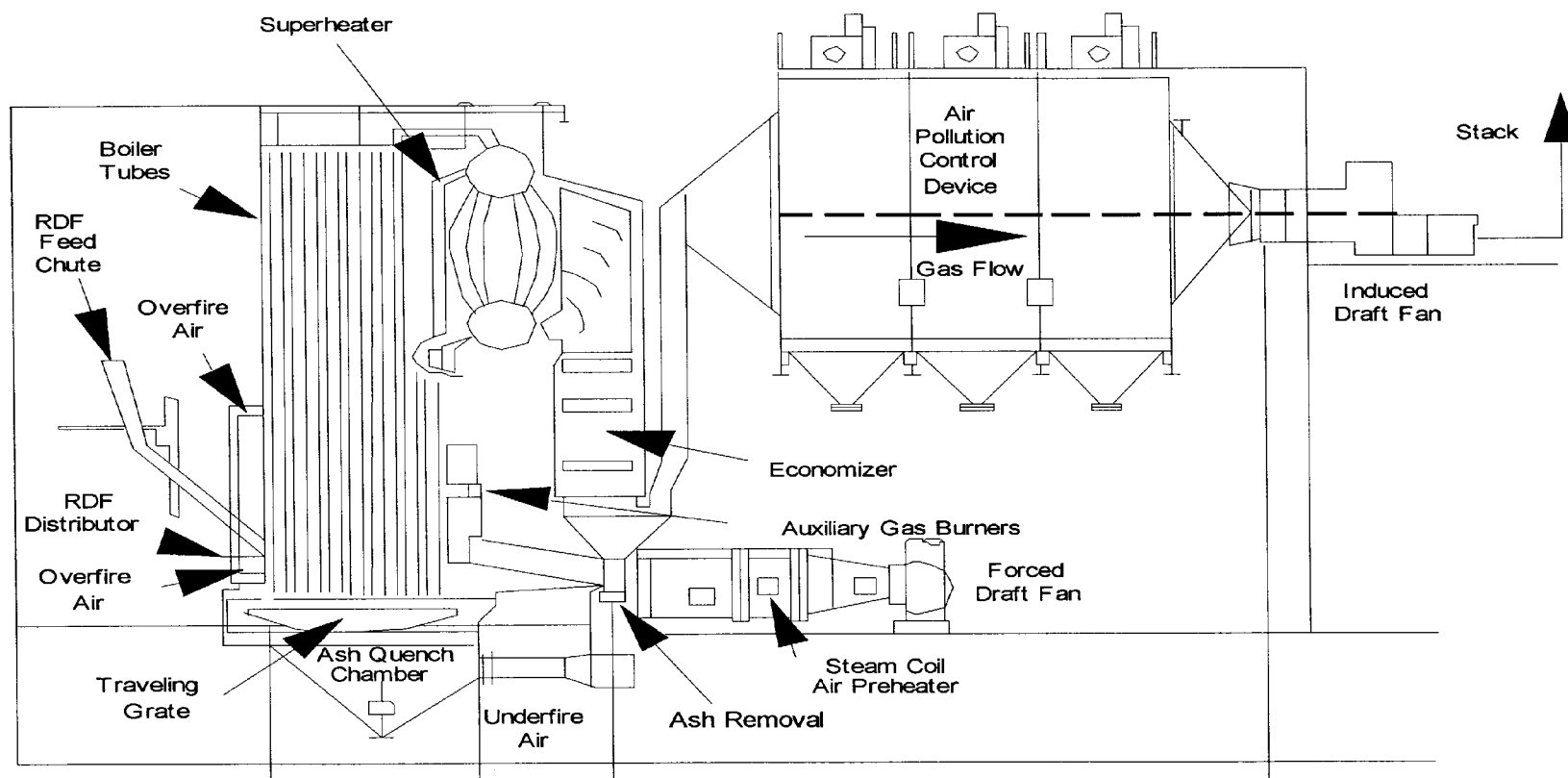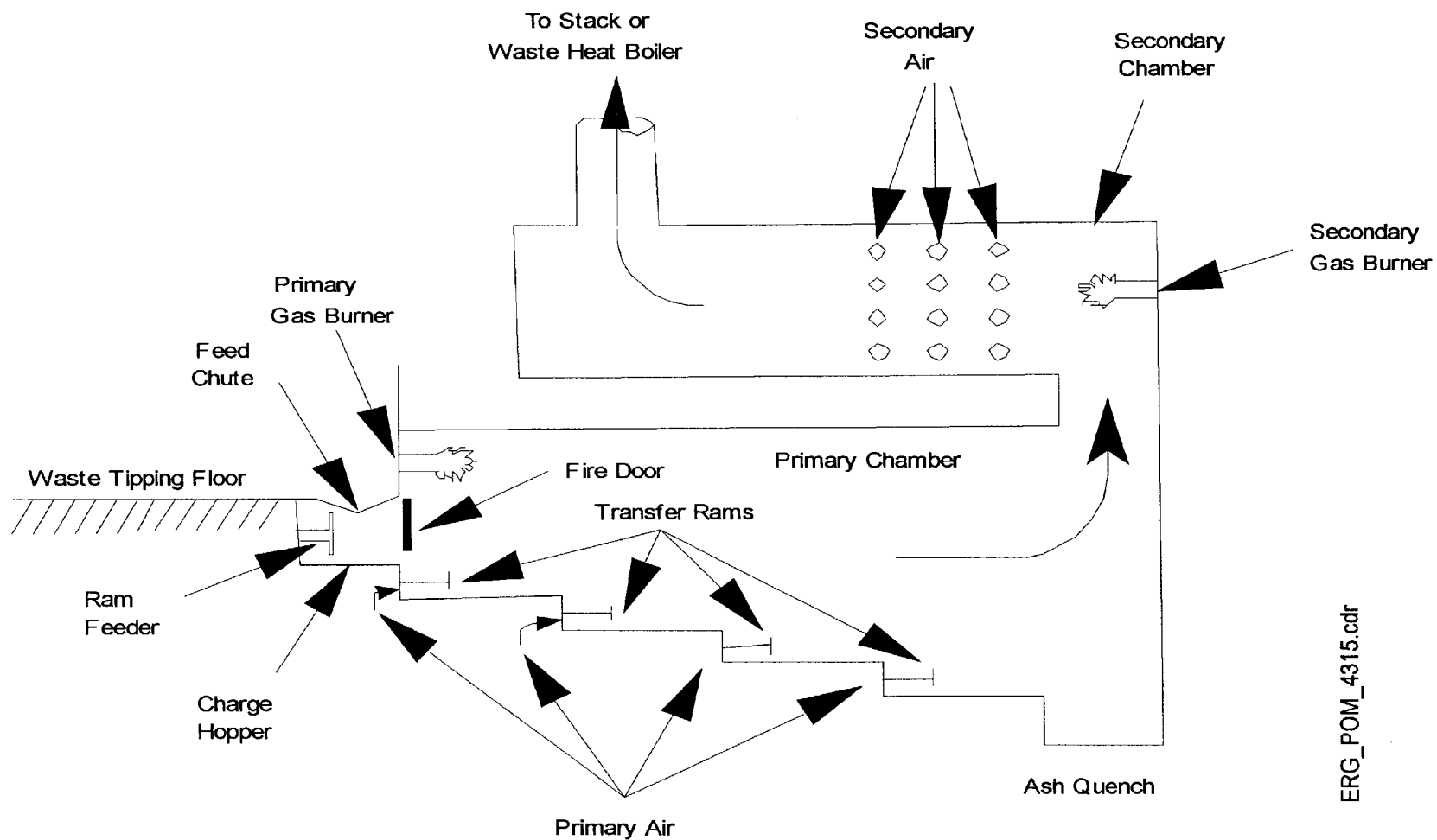
Figure 5-8. Typical RDF-Fired Spreader Stoker Boiler

Source: Reference 114.

Figure 5-9. Typical Modular Starved-Air Combustor with Transfer Rams

Source: Reference 114.

Emission Control Techniques

Lead is present in a variety of MSW streams, including paper, inks, batteries, and metal cans, but is most prevalent in plastics. Lead is used to make dyes and stabilizers that protect plastics from thermal and photo degradation. Because of the wide variability in MSW composition, lead emissions are highly variable and are independent of combustor type. Because the vapor pressure of lead is such that condensation develops onto particulates in the flue gas, lead can be effectively removed by a PM control device.[114]

Because lead is usually emitted from MWCs in particulate form, the control of lead is most frequently accomplished through the use of an ESP or fabric filter (FF), which are common PM control techniques. Although other PM control technologies (e.g., cyclones, electrified gravel beds, and venturi scrubbers) are available, they are not as effective as the ESP or FF at removing PM and so are seldom used on existing systems.[114] Well-designed ESPs and FFs operated at 450°F (230°C) or less remove over 97 percent of lead and other metals.[116]

The most common types of ESPs are plate-and-wire units, in which the discharge electrode is a bottom-weighted or rigid wire, and flat plate units, which use flat plates rather than wires as the discharge electrode. As a general rule, the greater the amount of collection plate area, the greater the PM collection efficiency. After the charged particles are collected on the grounded plates, the resulting dust layer is removed from the plates by rapping or washing and collected in a hopper. As the dust layer is removed, some of the collected PM becomes re-entrained in the flue gas. To ensure good PM collection efficiency during plate cleaning and electrical upsets, ESPs have several fields located in series along the direction of flue gas flow that can be energized and cleaned independently. Particles re-entrained when the dust layer is removed from one field can be recollected in a downstream field. Because of this phenomenon, increasing the number of fields generally improves PM removal efficiency.[114]

5.3.3 Emissions

Available lead emission factor data for several types of MWCs are provided in Table 5-21. The column labeled "Emission Source" identifies the main characteristics of each incinerator type. For some types of incinerators, a range of factors is provided that represents different sample test runs of the same source. Generally, there is a wide range in the emission factors associated with MWCs. This range is attributable to the variability of waste compositions and to the operating practices and effectiveness of control devices.[117] Waste composition can differ from one MWC unit to another, especially where the permit specifications for the accepted waste are different. For example, an MWC with a permit that prohibits the burning of lead-acid batteries will have lower lead emissions than an MWC with a permit that does not prohibit such burning. Because of this variability, the factors shown in Table 5-21 must be used cautiously and may not be representative of other MWCs.

5.4 INDUSTRIAL AND COMMERCIAL WASTE INCINERATION

5.4.1 Source Location

Commercial waste incinerators are generally located in urbanized, metropolitan areas with highly concentrated populations. Locations of industrial waste incinerators parallel those of the industries that use them for waste disposal. The lumber and wood products, primary metals, and printing industries are the greatest users of incinerators for waste disposal. Lumber and wood producers are primarily in the Southeast and Northwest. Primary metals plants are predominantly in the Midwest, the Mideast, and the Southwest. The printing industry is essentially distributed nationwide.[64] There are numerous industrial and commercial waste incinerators across the country; no specific information on locations of individual incinerators was identified.

TABLE 5-21. LEAD EMISSION FACTORS FOR MUNICIPAL WASTE COMBUSTION SOURCES

SCC Number	Emission Source	Control Device	Average Emission Factor in lb/ton (kg/Mg)[a]	Emission Factor Range in lb/ton (kg/Mg)[a]	Emission Factor Rating	Reference
5-01-001-01	Starved-Air: Multiple-Chamber	None	1.20×10^{-1} (6.00×10^{-2})	---	U	23
		ESP	2.82×10^{-3} (1.41×10^{-3})	---	C	114
5-01-001-02	Mass Burn: Single-Chamber	None	1.80×10^{-1} (9.00×10^{-2})	---	U	23
5-01-001-03	Refuse-derived Fuel	None	2.01×10^{-1} (1.00×10^{-1})	---	C	114
		ESP	3.66×10^{-3} (1.83×10^{-3})	---	A	114
		Spray Dryer/FF	1.04×10^{-3} (5.20×10^{-4})	---	D	114
		Spray Dryer/ESP	1.16×10^{-3} (5.80×10^{-4})	---	B	114
5-01-001-04	Mass Burn: Refractory Wall Combustor	None	2.13×10^{-1} (1.07×10^{-1})	---	A	114
		Spray Dryer/FF	2.61×10^{-4} (1.31×10^{-4})	---	A	114
		Spray Dryer/ESP	9.15×10^{-4} (4.58×10^{-4})	---	A	114
		Dry Sorbent Injection/FF	2.97×10^{-4} (1.49×10^{-4})	---	C	114
		Dry Sorbent Injection/ESP	2.90×10^{-3} (1.45×10^{-3})	---	E	114
		ESP	3.00×10^{-3} (1.50×10^{-3})	---	A	114

TABLE 5-21. LEAD EMISSION FACTORS FOR MUNICIPAL WASTE COMBUSTION SOURCES (CONTINUED)

SCC Number	Emission Source	Control Device	Average Emission Factor in lb/ton (kg/Mg)[a]	Emission Factor Range in lb/ton (kg/Mg)[a]	Emission Factor Rating	Reference
5-01-001-05	Mass Burn: Waterwall Combustor	None	2.13×10^{-1} (1.07×10^{-1})	---	A	114
		Spray Dryer/FF	2.61×10^{-4} (1.31×10^{-4})	---	A	114
		Spray Dryer/ESP	9.15×10^{-4} (4.58×10^{-4})	---	A	114
		Dry Sorbent Injection/FF	2.97×10^{-4} (1.49×10^{-4})	---	C	114
		Dry Sorbent Injection/ESP	2.90×10^{-3} (1.45×10^{-3})	---	E	114
		ESP	3.00×10^{-3} (1.50×10^{-3})	---	A	114
5-01-001-06	Mass Burn: Rotary Waterwall Combustor	None	2.13×10^{-1} (1.07×10^{-1})	---	A	114
		Spray Dryer/FF	2.61×10^{-4} (1.31×10^{-4})	---	A	114
		Spray Dryer/ESP	9.15×10^{-4} (4.58×10^{-4})	---	A	114
		Dry Sorbent Injection/FF	2.97×10^{-4} (1.49×10^{-4})	---	C	114
		Dry Sorbent Injection/ESP	2.90×10^{-3} (1.45×10^{-3})	---	E	114
		ESP	3.00×10^{-3} (1.50×10^{-3})	---	A	114

TABLE 5-21. LEAD EMISSION FACTORS FOR MUNICIPAL WASTE COMBUSTION SOURCES (CONTINUED)

SCC Number	Emission Source	Control Device	Average Emission Factor in lb/ton (kg/Mg)[a]	Emission Factor Range in lb/ton (kg/Mg)[a]	Emission Factor Rating	Reference
5-01-001-07	Modular Excess Air Combustor	None	2.13×10^{-1} (1.07×10^{-1})	---	A	114
		Spray Dryer/FF	2.61×10^{-4} (1.31×10^{-4})	---	A	114
		Spray Dryer/ESP	9.15×10^{-4} (4.58×10^{-4})	---	A	114
		Dry Sorbent Injection/FF	2.97×10^{-4} (1.49×10^{-3})	---	C	114
		Dry Sorbent Injection/ESP	2.90×10^{-3} (1.45×10^{-3})	---	E	114
		ESP	3.00×10^{-3} (1.50×10^{-3})	---	A	114

[a] Emission factors are expressed in lb (kg) of pollutant emitted per ton (Mg) of waste incinerated.

"---" means data are not available.

ESP = Electrostatic Precipitator.
FF = Fabric Filter.

5.4.2   Process Description

Similar to municipal waste incinerators, some solid waste is also incinerated in industrial and commercial facilities. Most individual waste incinerators at these sites are subject to State and local air quality regulations, such that these units have varying degrees of emissions control. Most incinerators are equipped with afterburners, and newer incinerators may have scrubbers or ESPs.[64]

Industrial wastes combusted in incinerators consist primarily of processing wastes and plant refuse containing paper, plastic, rubber, textiles, and wood. Because of the variety of manufacturing operations, waste composition is highly variable among plants, but may be fairly consistent within a plant. Industrial waste incinerators have basically the same design as small municipal waste incinerators. Available data indicate that approximately 91 percent of the units are multichamber designs, 8 percent are single-chamber designs, and 1 percent are rotary kiln or fluidized bed design.

About 1,500 of the estimated 3,800 industrial incinerators are used for volume reduction, 640 units (largely in the petroleum and chemical industries) are used for toxicity reduction, and the remaining 1,700 units are used for resource recovery, primarily at copper wire and electric motor plants.[64]

Commercial waste incinerators, typically small, multichamber incinerators, are used to reduce the volume of wastes from large office and living complexes, schools, and commercial facilities. Over 90 percent of such units require firing of an auxiliary fuel. Emissions controls are generally not present on commercial units.[64]

Lead emissions from industrial and commercial waste incineration are a function of waste composition, incinerator design and operating practices, and incinerator emissions control equipment. Both the incineration of wastes and the combustion of incinerator auxiliary fuel may be sources of lead emissions. Incinerator design and operating practices affect waste mixing, residence time in the flame zone, combustion stoichiometry, and other factors that contribute to

the amount of lead emissions generated. The type of emissions control used dictates whether lead in the form of PM or a gaseous pollutant is controlled and to what extent. Generally, lead emissions exist in both particulate and some gaseous forms, with available data indicating that particulate lead emissions often predominate. Incinerators with emission controls designed primarily for PM collection may be accomplishing most of the lead emissions control.

5.4.3 Emissions

At the time this report was compiled, there were no available emission factors for lead emissions from industrial/commercial waste incinerators. Most of the incinerators used by commercial and industrial facilities are multichamber designs. The process and control device configurations for incinerators at industrial and commercial facilities are the same as those used by municipalities. The emission factors for municipal incinerators, however, would not be accurate to use for industrial and commercial facilities because these two types of facilities incinerate different types of waste. The waste streams at industrial and commercial sites are highly variable. One plant might burn wood protected with lead-based paint, which would yield high lead emissions. Another plant might burn wooden boxes and pallets that have low lead content. As a result, very little data has been developed that accurately characterizes lead emissions from industrial/commercial incinerators.

5.5 SEWAGE SLUDGE INCINERATORS

5.5.1 Source Location

There are approximately 200 sewage sludge incineration plants operating in the United States.[118] Most sewage sludge incinerators (SSIs) are located in the eastern United States, although there are a significant number on the West Coast. New York has the largest number of facilities with 33; Pennsylvania and Michigan have the next largest number with 21 and 19 sites, respectively.[119]

5.5.2   Process Description

        The first step in the process of sewage sludge incineration is dewatering the sludge. Sludge is generally dewatered until it is about 15 to 30 percent solids, at which point it will burn without supplemental fuel. After dewatering, the sludge is sent to the incinerator for combustion. The two main types of SSIs currently in use are the multiple-hearth furnace (MHF) and the fluidized-bed combustor (FBC). Over 80 percent of the identified operating SSIs are MHFs and about 15 percent are FBCs. The remaining SSIs co-fire MSW with sludge.[120]

        Multiple-Hearth Furnaces

        A cross-sectional diagram of a typical MHF is shown in Figure 5-10. The basic MHF is a vertically oriented cylinder. The outer shell is constructed of steel and lined with refractory material and surrounds a series of horizontal refractory hearths. A hollow cast iron rotating shaft runs through the center of the hearths. Cooling air is introduced into the shaft, which extends above the hearths. Attached to the central shaft are the rabble arms, which extend above the hearths. Each rabble arm is equipped with a number of teeth approximately 6 inches in length and spaced about 10 inches apart. The teeth are shaped to rake the sludge in a spiral motion, alternating in direction from the outside in to the inside out between hearths. Burners, which provide auxiliary heat, are located in the sidewalls of the hearths.

        In most MHFs, partially dewatered sludge is fed onto the perimeter of the top hearth. The rabble arms move the sludge through the incinerator by raking the sludge toward the center shaft, where it drops through holes located at the center of the hearth. In the next hearth, the sludge is raked in the opposite direction. This process is repeated in all of the subsequent hearths. The effect of the rabble motion is to break up solid material to allow better surface contact with heat and oxygen. A sludge depth of about 1 inch is maintained in each hearth at the design sludge flow rate.

        Under normal operating conditions, 50 to 100 percent excess air must be added to an MHF to ensure complete combustion of the sludge. Besides enhancing contact between the
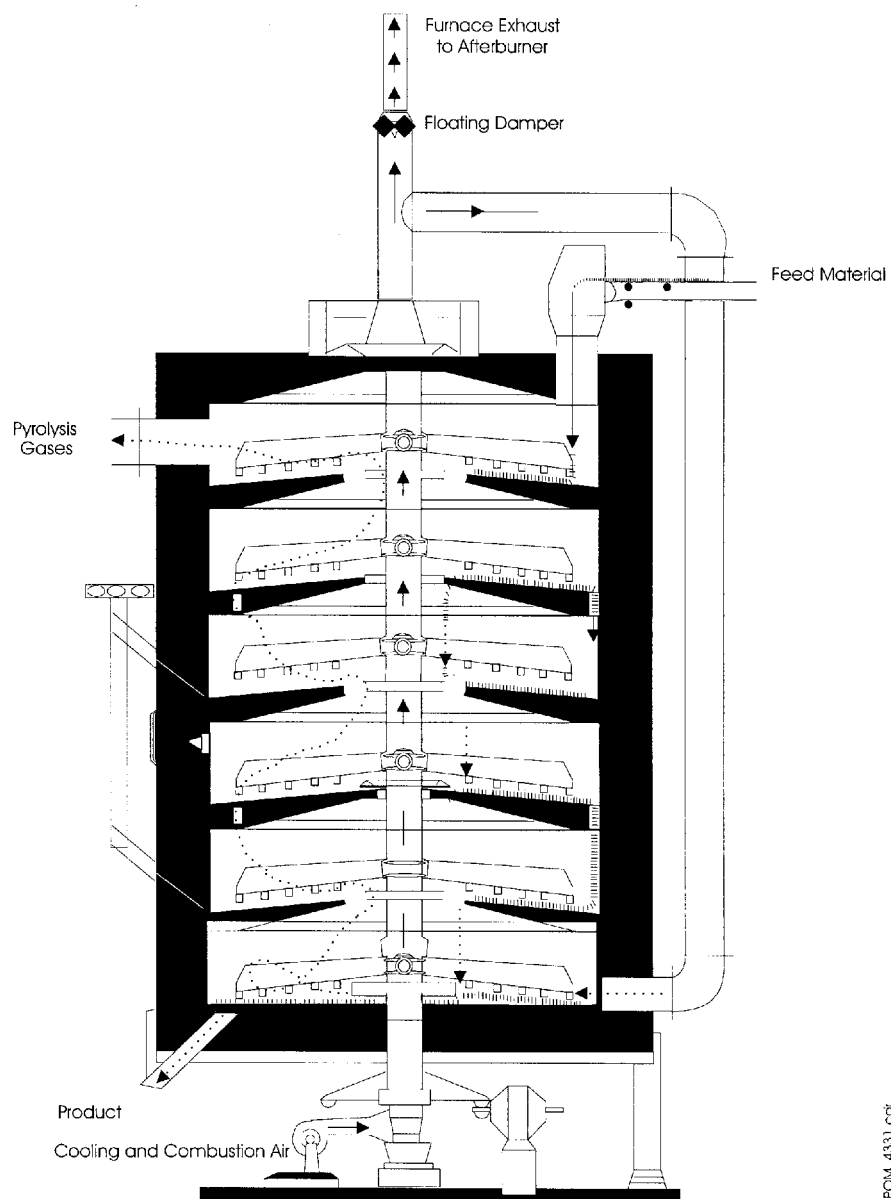
Figure 5-10. Typical Multiple-Hearth Furnace

Source: Reference 120.

fuel and the oxygen in the furnace, these relatively high rates of excess air are necessary to compensate for normal variations in both the organic characteristics of the sludge feed and the rate at which it enters the incinerator. When an inadequate amount of excess air is available, only partial oxidation of the carbon will occur, with a resultant increase in emissions of CO, soot, and hydrocarbons. Too much excess air, on the other hand, can cause increased entrainment of particulate and unnecessarily high auxiliary fuel consumption.[120]

Fluidized-Bed Combustors

Figure 5-11 shows the cross-section diagram of an FBC. FBCs consist of a vertically oriented outer shell constructed of steel and lined with refractory material. Tuyeres (nozzles designed to deliver blasts of air) are located at the base of the furnace within a refractory-lined grid. A bed of sand approximately 2.5 feet (0.75 meters) thick rests upon the grid. Two general configurations can be distinguished based on how the fluidizing air is injected into the furnace. In the hot windbox design, the combustion air is first preheated by passing it through a heat exchanger, where heat is recovered from the hot flue gases. Alternatively, ambient air can be injected directly into the furnace from a cold windbox.

Partially dewatered sludge is fed into the lower portion of the furnace. Air injected through the tuyeres at a pressure of 3 to 5 pounds per square inch gauge (20 to 35 kilopascals) simultaneously fluidizes the bed of hot sand and the incoming sludge. Temperatures of 1,400 to 1,700°F (750 to 925°C) are maintained in the bed. As the sludge burns, fine ash particles are carried out of the top of the furnace. Some sand is also removed in the air stream and must be replaced at regular intervals.

Combustion of the sludge occurs in two zones. Within the sand bed itself (the first zone), evaporation of the water and pyrolysis of the organic materials occur nearly simultaneously as the temperature of the sludge is rapidly raised. In the freeboard area (the second zone), the remaining free carbon and combustible gases are burned. The second zone functions essentially as an afterburner.
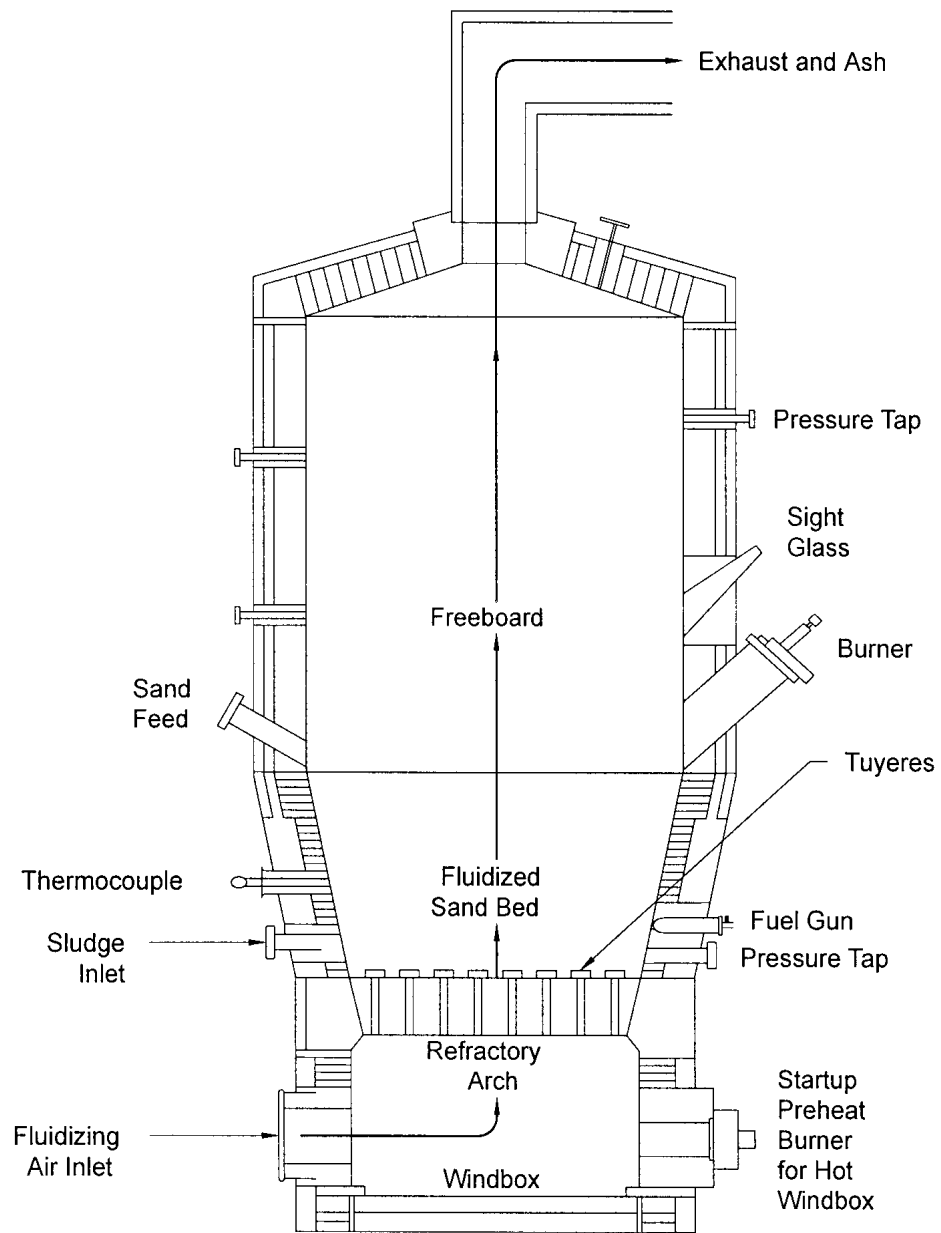
Figure 5-11. Fluidized-Bed Combustor

Source: Reference 120.

Fluidization achieves nearly ideal mixing between the sludge and the combustion air; the turbulence facilitates the transfer of heat from the hot sand to the sludge. A FBC improves the burning atmosphere, such that a limited amount of excess air is required for complete combustion of the sludge. Typically, FBCs can achieve complete combustion with 20 to 50 percent excess air, about half the excess air required by MHFs. As a consequence, FBCs generally have lower fuel requirements than MHFs.[120]

Emission Control Techniques

The emission rates of lead in SSIs are affected by the following conditions:

- Sludge metal content;

- Operating bed temperature;

- Sludge chlorine content;

- Flow patterns leading to solids drop-out ahead of APCD; and

- APCD control efficiency as a function of particle size.

Clearly, the quantity of lead in the feed sludge is the basic scalar of emissions. Lead in sludge arises from several sources, including industrial discharges (especially plating wastes), corrosion of outtake plumbing materials, street runoff (especially deposited lead compounds from lead-containing paints), and numerous lesser domestic and industrial activities. The lead content varies from day to day, reflecting a diversity of waste types.

The temperature of the combustion environment influences the behavior of lead emissions because of the following sequence of events during incineration:

1. At elevated temperatures, many heavy metal compounds (including lead) vaporize. The higher the temperature, the larger the fraction of lead that is vaporized.

2. As temperatures drop, a fraction of the lead condenses. Condensation takes place in proportion to available surface area.

3.   Collection of the lead condensed on the PM occurs while passing through the APCD system.

Sludge chlorine content increases the sensitivity of lead emissions to bed temperature, such that the lead volatilizes at a lower temperature than if there were no chlorine in the sludge. This behavior is due to the high volatility of the metal chlorides ($PbCl_2$) versus metal oxides (PbO).[60] Monitoring and limiting the sludge chlorine content allows more lead to condense onto PM for more effective lead emissions control.

Lead emissions may be reduced by using PM control devices, reducing incinerator and APCD temperatures, and controlling sludge chlorine content. The types of existing SSI PM controls include low-pressure-drop spray towers, wet cyclones, high-pressure-drop venturi scrubbers, and venturi/impingement tray scrubber combinations. A few ESPs and baghouses are employed, primarily where sludge is co-fired with MSW. The most widely used PM control device applied to an MHF is the impingement tray scrubber. Older units use the tray scrubber alone; combination venturi/impingement tray scrubbers are widely applied to newer MHFs and some FBCs.[120]

5.5.3   Emissions

Table 5-22 presents lead emission factors for SSIs. The factors presented cover the two main incinerator types: MHFs and FBCs. Again, as the emission factor tables for the other types of incinerators (previously discussed) show, PM type control technologies offer the greatest efficiency for reducing lead emissions.

5.6   MEDICAL WASTE INCINERATION

Medical waste incinerators (MWIs) burn both infectious ("red bag" and pathological) medical wastes and non-infectious general hospital wastes. The primary purposes of MWIs are to (1) render the waste innocuous, (2) reduce the volume and mass of the waste, and (3) provide waste-to-energy conversion.

TABLE 5-22. LEAD EMISSION FACTORS FOR SEWAGE SLUDGE INCINERATOR SOURCES

SCC Number	Emission Source	Control Device	Average Emission Factor in lb/ton (kg/Mg)[a]	Emission Factor Range in lb/ton (kg/Mg)[a]	Emission Factor Rating	Reference
5-01-005-15	Multiple-hearth Furnace	None	1.00×10^{-1} (5.00×10^{-2})	---	B	120
		Single Cyclone/Venturi Scrubber	6.00×10^{-3} (3.00×10^{-3})	---	E	120
		Single Cyclone	6.00×10^{-2} (3.00×10^{-2})	---	E	120
		ESP	2.00×10^{-3} (1.00×10^{-3})	---	E	120
		Venturi Scrubber	1.80×10^{-3} (9.00×10^{-4})	---	E	120
		Venturi Scrubber/Wet ESP	1.80×10^{-4} (9.00×10^{-5})	---	E	120
		Venturi Scrubber/ Impingement-type Wet Scrubber	6.00×10^{-2} (3.00×10^{-2})	---	B	120
		Venturi Scrubber/ Impingement-type Wet Scrubber/Afterburner	1.00×10^{-1} (5.00×10^{-2})	---	E	120
		Impingement-type Wet Scrubber	4.00×10^{-2} (2.00×10^{-2})	---	E	120
		Single Cyclone/Venturi Scrubber/Impingement Scrubber	2.20×10^{-2} (1.10×10^{-2})	---	E	120

TABLE 5-22. LEAD EMISSION FACTORS FOR SEWAGE SLUDGE INCINERATOR SOURCES (CONTINUED)

SCC Number	Emission Source	Control Device	Average Emission Factor in lb/ton (kg/Mg)[a]	Emission Factor Range in lb/ton (kg/Mg)[a]	Emission Factor Rating	Reference
5-01-005-16	Fludized Bed	None	4.00×10^{-2} (2.00×10^{-2})	---	E	120
		FF	1.00×10^{-5} (5.00×10^{-6})	---	E	120
		Impingement-type Wet Scrubber	6.00×10^{-3} (3.00×10^{-3})	---	E	120
		Venturi Scrubber Impingement-type Wet Scrubber	1.60×10^{-1} (8.00×10^{-2})	---	E	120
		Venturi Scrubber/ Impingement-type Wet Scrubber/ESP	2.00×10^{-6} (1.00×10^{-6})	---	E	120

5.6.1   Source Location

There are an estimated 6,000 MWIs in the United States, located at such facilities as hospitals, pharmaceutical companies, research facilities, nursing homes, and other institutions and companies that incinerate medical waste.[55] It is estimated that 90 percent of the nation's 6,872 hospitals (where the majority of MWIs are located) have some type of on-site incinerator, if only a small unit for incinerating special or pathological waste.[55]

5.6.2   Process Description

Three main types of incinerators are used as MWIs: controlled-air or starved-air, excess-air, and rotary kiln. The majority (>95 percent) of incinerators are controlled-air units. A small percentage (<2 percent) are excess-air, and less than 1 percent were identified as rotary kiln. The rotary kiln units tend to be larger and typically are equipped with air pollution control devices. Approximately two percent of all MWIs are equipped with air pollution control devices.[121]

Controlled-Air Incinerators

Controlled-air incineration is the most widely used MWI technology, and now dominates the market for new systems at hospitals and similar medical facilities. This technology is also known as two-stage incineration or modular combustion. Figure 5-12 presents a schematic diagram of a typical controlled-air unit.[121]

Combustion of waste in controlled-air incinerators occurs in two stages. In the first stage, waste is fed into the primary, or lower, combustion chamber, which is operated with less than the stoichiometric amount of air required for combustion. Combustion air enters the primary chamber from beneath the incinerator hearth (below the burning bed of waste). This air is called primary or underfire air. In the primary (starved-air) chamber, the low air-to-fuel ratio dries and facilitates volatilization of the waste and most of the residual carbon in the ash burns.
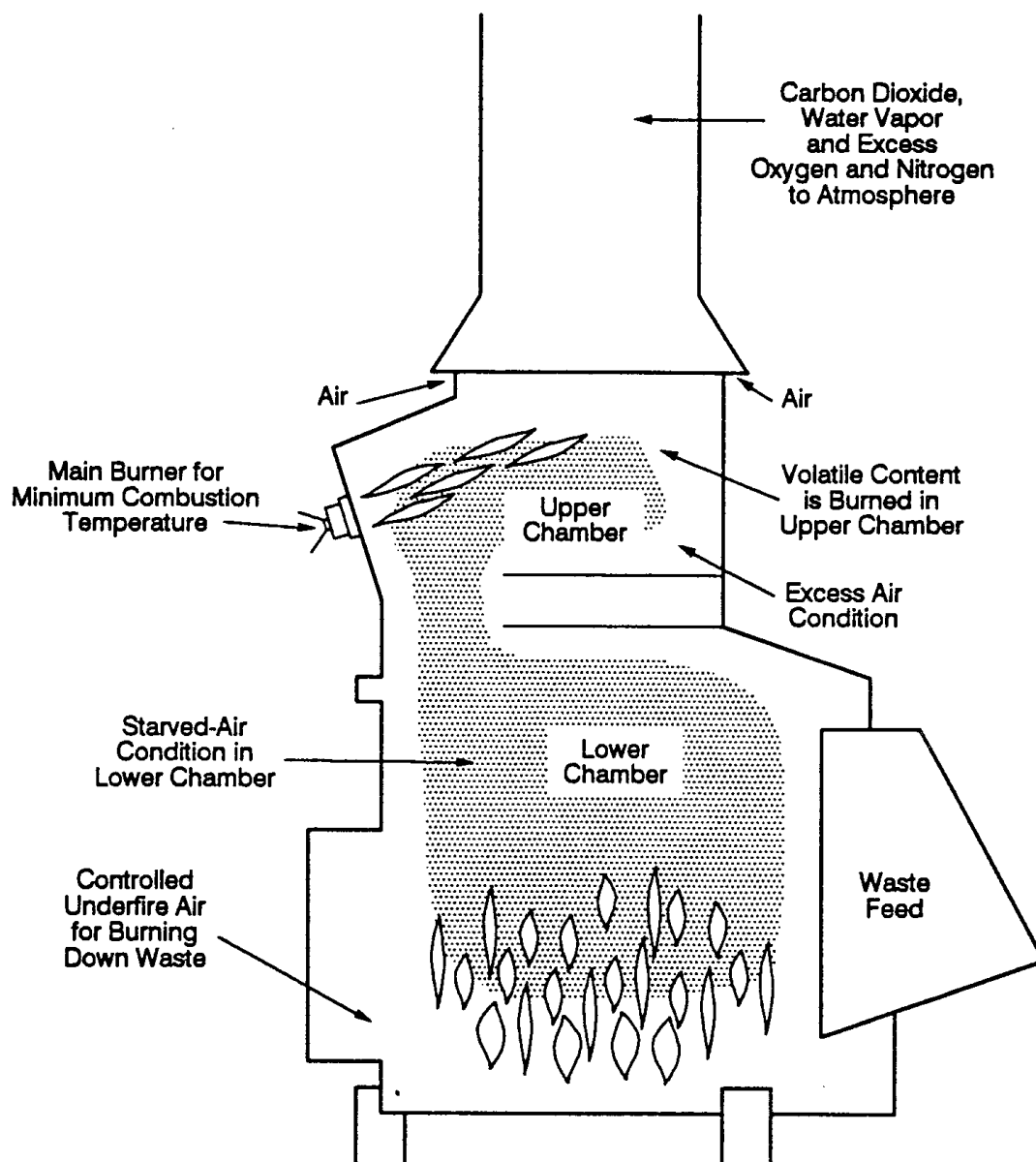
Figure 5-12. Controlled-Air Incinerator

Source: Reference 121.

At these conditions, combustion gas temperatures are relatively low (1,400 to 1,800°F [760 to 980°C]).[121]

In the second stage, excess air is added to the volatile gases formed in the primary chamber to complete combustion. Secondary chamber temperatures are higher than primary chamber temperatures--typically 1,800 to 2,000°F (980 to 1,095°C). Depending upon the heating value and moisture content of the waste, additional heat may be needed. Additional heat can be provided by auxiliary burners located at the entrance to the secondary (upper) chamber to maintain desired temperatures.[121]

Waste feed capacities for controlled-air incinerators range from about 75 to 6,500 lb/hr (0.6 to 50 kg/min) (at an assumed fuel heating value of 8,500 Btu/lb [19,700 kJ/kg]). Waste feed and ash removal can be manual or automatic, depending on the unit size and options purchased. Throughput capacities for lower-heating-value wastes may be higher because feed capacities are limited by primary chamber heat release rates. Heat release rates for controlled-air incinerators typically range from about 15,000 to 25,000 Btu/hr-ft^3 (430,000 to 710,000 kJ/hr-m^3).[121]

Excess-Air Incinerators

Excess-air incinerators are typically small, modular units. They are also referred to as batch incinerators, multiple-chamber incinerators, or "retort" incinerators. Excess-air incinerators are typically a compact cube with a series of internal chambers and baffles. Although they can be operated continuously, they are usually operated in batch mode.[121]

Figure 5-13 presents a schematic for an excess-air unit. Typically, waste is manually fed into the combustion chamber. The charging door is then closed, and an afterburner is ignited to bring the secondary chamber to a target temperature (typically 1,600 to 1,800°F [870 to 980°C]). When the target temperature is reached, the primary chamber burner ignites. The waste is dried, ignited, and combusted by heat provided by the primary chamber burner, as well as by radiant heat from the chamber walls. Moisture and volatile components in the waste
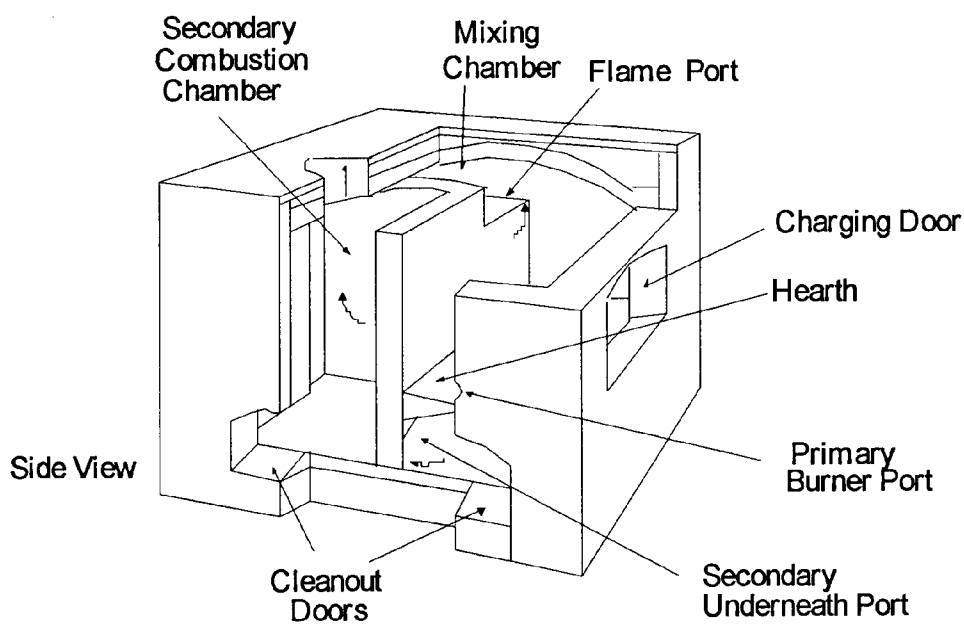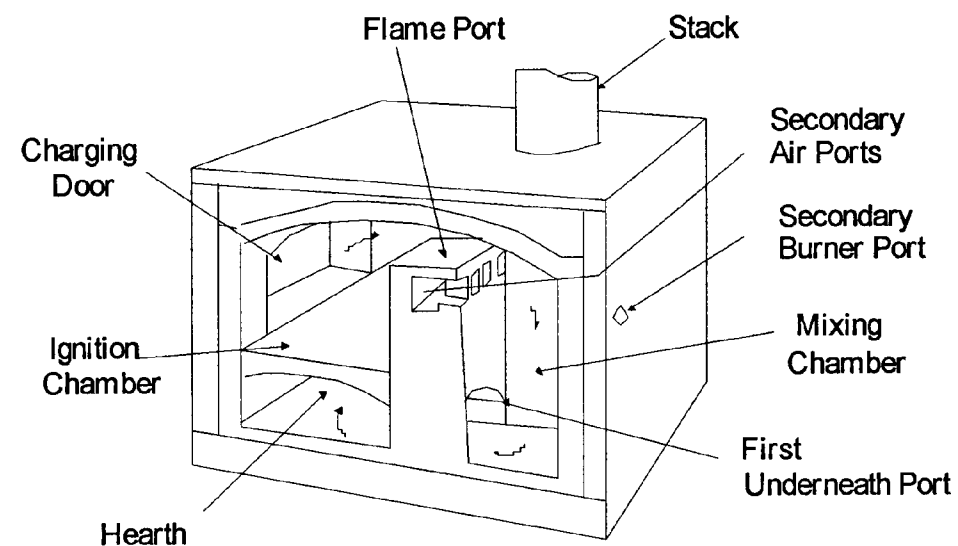
Figure 5-13. Excess-Air Incinerator

Source: Reference 121.

are vaporized and pass (along with combustion gases) out of the primary chamber and through a flame port that connects the primary chamber to the secondary or mixing chamber. Secondary air is added through the flame port and is mixed with the volatile components in the secondary chamber. Burners are also installed in the secondary chamber to maintain adequate temperatures for combustion of volatile gases. Gases exiting the secondary chamber are directed to the incinerator stack or to an air pollution control device. After the chamber cools, ash is manually removed from the primary chamber floor and a new charge of waste can be added.[121]

Incinerators designed to burn general hospital waste operate at excess air levels of up to 300 percent. If only pathological wastes are combusted, excess air levels near 100 percent are more common. The lower excess air helps maintain higher chamber temperature when burning high-moisture waste. Waste feed capacities for excess-air incinerators are usually 500 lb/hr (3.8 kg/min) or less.[121]

Rotary Kiln Incinerators

Rotary kiln incinerators are also designed with a primary chamber, where the waste is heated and volatilized, and a secondary chamber, where combustion of the volatile fraction is completed. The primary chamber consists of a slightly inclined, rotating kiln in which waste materials migrate from the feed end to the ash discharge end. The waste throughput rate is controlled by adjusting the rate of kiln rotation and the angle of inclination. Combustion air enters the primary chamber through a port. An auxiliary burner generally is used to start combustion and maintain desired combustion temperatures.

Figure 5-14 presents a schematic diagram of a typical rotary kiln incinerator. Volatiles and combustion gases pass from the primary chamber to the secondary chamber. The secondary chamber operates at excess air. Combustion of the volatiles is completed in the secondary chamber. Because of the turbulent motion of the waste in the primary chamber, solids burnout rates and particulate entrainment in the flue gas are higher for rotary kiln incinerators than for other incinerator designs. As a result, rotary kiln incinerators generally have add-on gas-cleaning devices.[121]
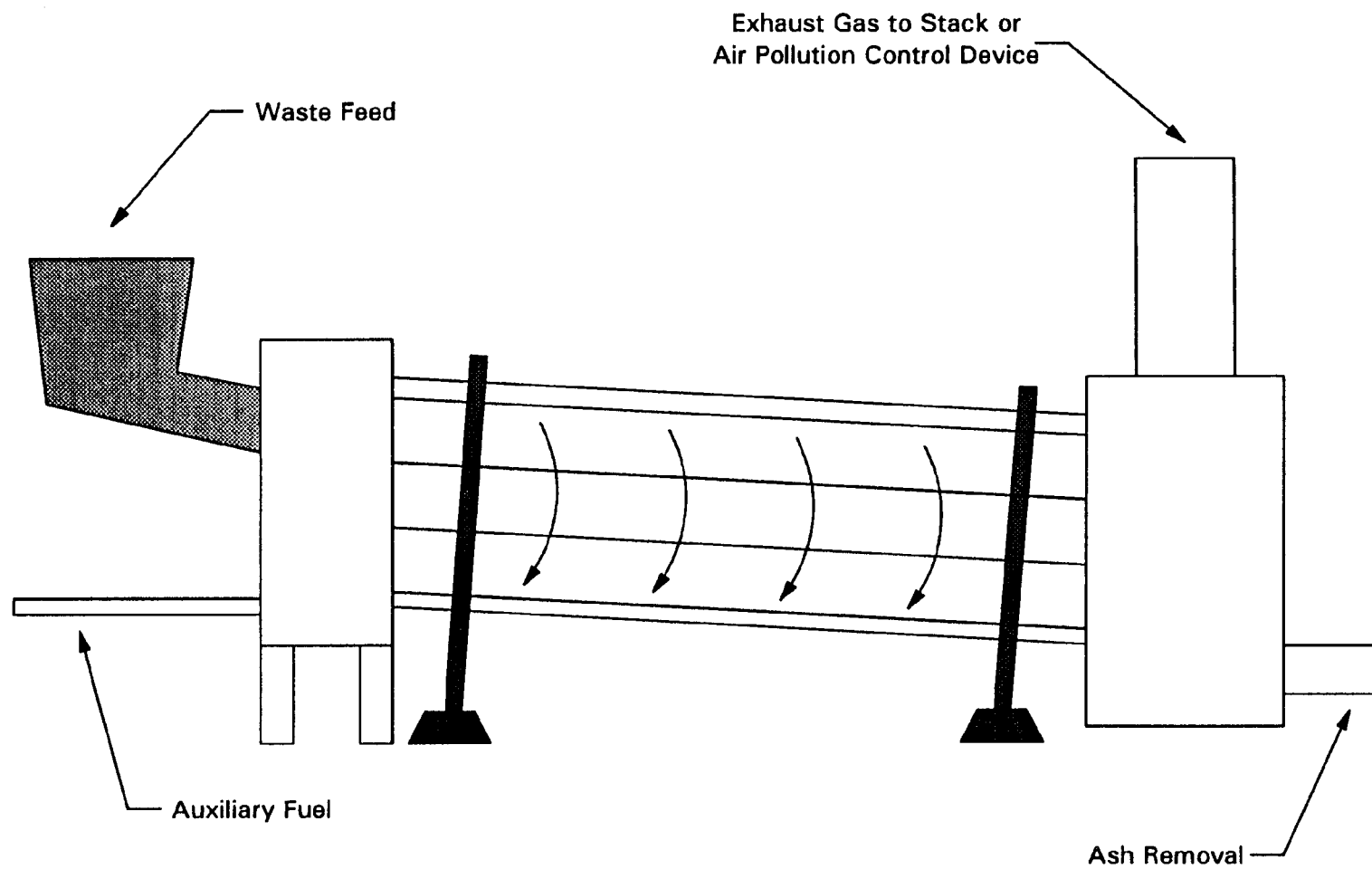
Exhaust Gas to Stack or
Air Pollution Control Device

Waste Feed

Auxiliary Fuel

Ash Removal

Figure 5-14. Rotary Kiln Incinerator

Emission Control Techniques

Medical waste contains toxic metals such as lead. Lead is found in many materials, including plastics, paper, inks, and electrical cable insulation. However, the primary source of lead appears to be plastics. Lead is used to make dyes and stabilizers that protect plastics from thermal and photo-degradation. The dyes made from lead are used to color plastic bags; thus, some of the lead emissions from MWIs could be due simply to the "red bags" that infectious waste is placed in. During incineration, lead only changes forms (chemical and physical states) but is not destroyed. Lead can be emitted from incinerators on small particles capable of penetrating deeply into human lungs.[122]

A majority of lead and other metal emissions is in the form of PM, and a minority is in vapor form. Particulate emissions of lead from the incineration of medical wastes are determined by three major factors:

1. Suspension of noncombustible inorganic materials containing lead;

2. Incomplete combustion of combustible lead materials; and

3. Condensation of lead-based vaporous materials (these materials are mostly inorganic matter).

Emissions of noncombustible materials result from the suspension or entrainment of ash by the combustion air added to the primary chamber of an incinerator. The more air that is added, the more likely that noncombustibles become entrained. Particulate emissions from incomplete combustion of combustible materials result from improper combustion control of the incinerator. Condensation of vaporous materials results from noncombustible substances that volatilize at primary combustion chamber temperatures with subsequent cooling in the flue gas. These materials usually condense on the surface of other fine particles.[122]

Typically, two strategies are used to minimize metals emissions: (1) combustion control in the primary chamber so as to inhibit vaporization or entrainment of metals, and

(2) capture of any metals that do escape by APCDs. Both of these strategies are discussed below. The key APCD parameters used are specific to the device that is used.

    Combustion Control--Most MWIs are simple single-chamber units with an afterburner located in the stack. The ability of batch incinerators to control lead emissions is limited because only the temperature in the stack is usually monitored.

    Most new incinerators are starved-air units. The primary chamber is designed to operate at low temperatures and low gas flow rates. This minimizes the amount of materials entrained or vaporized.

    To ensure that lead emissions are minimized, operators must maintain the primary chamber at the temperatures and gas flow rates for which it was designed. Usually the only parameter that system operators can directly control is feed rate. High feed rates can lead to high temperatures and high gas velocities. Thus, many operators carefully control the feed rate. The feed rate is reduced when primary temperatures increase. Keeping the temperature low enables the lead to condense on different sizes of particles, which are then easily trapped by PM control devices.

    APCD Control--When lead reaches the APCD, it is present in one of three forms. Non-volatile lead is present on large entrained particles. Lead that has vaporized and recondensed is usually enriched on fly-ash particles with diameters less than 1 micron. Extremely volatile lead is present as vapor.[122] The majority of lead emissions are in the first two forms and are controlled by PM control devices. Generally, particulate control is a surrogate for lead control in an incinerator/air pollution control system.[55]

5.6.3   Emissions

    The available lead emission factors for MWIs are presented in Table 5-23. As with the other types of incinerators, waste composition is a critical factor in the amount of lead emitted from MWIs.

TABLE 5-23. LEAD EMISSION FACTORS FOR MEDICAL WASTE COMBUSTION SOURCES

SCC Number	Emission Source	Control Device	Average Emission Factor in lb/ton (kg/Mg)[a]	Emission Factor Range in lb/ton (kg/Mg)[a]	Emission Factor Rating	Reference
5-01-005-05	Other Incineration Pathological/Rotary Kiln	None	1.24×10^{-1} (6.20×10^{-2})	---	E	121
5-01-005-05	Other Incineration Pathological/ Controlled Air	None	7.28×10^{-2} (3.64×10^{-2})	---	B	121
5-01-005-05	Other Incineration Pathological	Wet Scrubber - High Efficiency	6.98×10^{-2} (3.49×10^{-2})	---	E	121
		Wet Scrubber - Medium Efficiency/FF	1.60×10^{-3} (8.00×10^{-4})	---	E	121
		FF	9.92×10^{-5} (4.96×10^{-5})	---	E	121
		Spray Dryer/ FF	1.89×10^{-4} (9.45×10^{-5})	---	E	121
		Spray Dryer/Carbon Injection/FF	7.38×10^{-5} (3.69×10^{-5})	---	E	121
		Dry Sorbent Injection/ ESP	4.70×10^{-3} (2.35×10^{-3})	---	E	121
		Dry Sorbent Injection/FF	6.25×10^{-5} (3.12×10^{1})	---	E	121
		Dry Sorbent Injection/ Carbon Injection/FF	9.27×10^{-5} (4.64×10^{-5})	---	E	121
		Dry Sorbent Injection/FF/Scrubber	5.17×10^{-5} (2.59×10^{-5})	---	E	121
		Wet Scrubber - Low Efficiency	7.94×10^{-2} (3.97×10^{-2})	---	E	121

SCC Number	Emission Source	Control Device	Average Emission Factor in lb/ton (kg/Mg)[a]	Emission Factor Range in lb/ton (kg/Mg)[a]	Emission Factor Rating	Reference
5-02-005-05	Commercial - Incineration - Pathological	None (Rotary Kiln Incinerator)	1.24×10^{-1} (6.20×10^{-2})	---	E	121
		Afterburner	6.50×10^{-4} (3.30×10^{-4})	5.30×10^{-4} - 7.60×10^{-4} $(2.70 \times 10^{-4}$ - $3.80 \times 10^{-4})$	E	123
		FF	9.92×10^{-5} (4.96×10^{-5})	---	E	121
		Wet Scrubber - High Efficiency	6.98×10^{-2} (3.49×10^{-2})	---	E	121
		Wet Scrubber - Medium Efficiency/FF	1.60×10^{-3} (8.00×10^{-4})	---	E	121
		Spray Dryer/FF	1.89×10^{-4} (9.45×10^{-5})	---	E	121
		Spray Dryer/Carbon Injection/FF	7.38×10^{-5} (3.69×10^{-5})	---	E	121
		Dry Sorbent Injection/ESP	4.70×10^{-3} (2.35×10^{-3})	---	E	121
		Dry Sorbent Injection/Carbon Injection/FF	9.27×10^{-5} (4.64×10^{-5})	---	E	121
		Dry Sorbent Injection/FF	6.25×10^{-5} (3.13×10^{-5})	---	E	121
		None (Controlled Air Incinerator)	7.28×10^{-2} (3.64×10^{-2})	---	B	121
		Dry Sorbent Injection/ FF/Scrubber	5.17×10^{-5} (2.59×10^{-5})	---	E	121

TABLE 5-23. LEAD EMISSION FACTORS FOR MEDICAL WASTE COMBUSTION SOURCES (CONTINUED)

SCC Number	Emission Source	Control Device	Average Emission Factor in lb/ton (kg/Mg)[a]	Emission Factor Range in lb/ton (kg/Mg)[a]	Emission Factor Rating	Reference
5-02-005-05 (continued)	Commercial - Incineration - Pathological	Wet Scrubber - Low Efficiency	7.94×10^{-2} (3.97×10^{-2})	---	E	121

[a] Emission factors are expressed in lb (kg) of pollutant emitted per ton (Mg) of waste incinerated.

"---" means data are not available.

ESP = Electrostatic Precipitator.
FF = Fabric Filter.

The lead emission factors were developed from tests at facilities burning red bag waste, pathological waste, and/or general hospital waste. Red bag waste is defined as any waste generated in the diagnosis or immunization of human beings or animals; pathological waste is defined as any human and animal remains, tissues, and cultures; and general hospital waste was defined as a mixture of red bag waste and municipal waste generated by the hospital.

As with other combustion sources, the presented emission factors are highly dependent upon the composition of the waste. For example, the difference in the emission factors presented in Table 5-23 for both a high efficiency and medium efficiency wet scrubber applied to an MWI is expected to be more a function of the lead content of the waste burned than scrubber efficiency.

5.7   HAZARDOUS WASTE INCINERATION

Hazardous waste, as defined by 40 CFR Part 261, includes a wide variety of waste materials.[124] Hazardous wastes are produced in the form of liquids (e.g., waste oils, halogenated and nonhalogenated solvents, other organic liquids, and pesticides/herbicides) and sludges and solids (e.g., halogenated and nonhalogenated sludges and solids, dye and paint sludges, resins, and latex). The lead content of hazardous waste varies widely, but lead could be emitted from the incineration of any of these types of hazardous waste. Based on a 1986 study, total annual hazardous waste generation in the United States was approximately 292 million tons (265 million metric tons).[125] Only a small fraction of the waste (less than 1 percent) was incinerated. MACT standards for hazardous waste combustors and Portland cement manufacturing were proposed May 2, 1997 and March 24, 1998, respectively. These proposed standards should reduce lead emissions.

Based on an EPA study conducted in 1983, the major types of hazardous waste streams incinerated were spent nonhalogenated solvents and corrosive and reactive wastes contaminated with organics. Together, these accounted for 44 percent of the waste incinerated. Other prominent wastes included hydrocyanic acid, acrylonitrile bottoms, and nonlisted ignitable wastes.[126]

Industrial kilns, boilers, and furnaces are used to burn hazardous waste. They use the hazardous waste as fuel to produce commercial products such as cement, lime, iron, asphalt, or steam. In fact, the majority of hazardous waste generated in the United States is currently disposed of in cement kilns. Lead emissions from cement kilns are discussed in Section 5.13. Hazardous waste, which is an alternative to fossil fuels for energy and heat, is used at certain commercial facilities as a supplemental fuel. In the process of producing energy and heat, the hazardous wastes are subjected to high temperatures for a sufficient time to volatilize metals in the waste.

5.7.1   Source Location

Currently, 162 permitted or interim status incinerator facilities, having 190 units, are in operation in the United States. Another 26 facilities are proposed (i.e., new facilities under construction or permitting).[127] Of the above 162 facilities, 21 facilities are commercial facilities that burn about 700,000 tons of hazardous waste annually.[128] The remaining 141 are on-site or captive facilities and burn about 800,000 tons of waste annually.

5.7.2   Process Description

Hazardous waste incineration employs oxidation at high temperatures (usually 1,650°F [900°C] or greater) to destroy the organic fraction of the waste and reduce volume. A diagram of the typical process component options in a hazardous waste incineration facility is provided in Figure 5-15. The diagram shows the major subsystems that may be incorporated into a hazardous waste incineration system: waste preparation and feeding, combustion chamber(s), air pollution control, and residue/ash handling.

Five types of hazardous waste incinerators are currently available and in operation: liquid injection, rotary kiln, fixed-hearth, fluidized-bed, and fume injection.[129]

Waste Preparation

Blending   Atomization
Screening   Ram
Shredding   Gravity
Heating   Auger
               Lance

Combustion

Liquid Injection
Rotary Kiln
Fixed Hearth
Fluidized Bed

Air Pollution Control

Quench   Venturi   Packed Tower
Heat   Wet ESP*   Spray Tower
Recovery   IWS*   Tray Tower
             Fabric Filter IWS
                      Wet ESP

Waste →

Waste Preparation → Waste Feeding → Combustion Chamber(s) → Combustion Gas Conditioning → Particulate Removal → Acid Gas Removal → Demister and Stack

* IWS = Ionizing Wet Scrubber
ESP = Electrostatic Precipitator
POTW = Publically Owned
        Treatment Works

Ash Disposal

Residue Treatment

Residue and Ash Handling

Return to Process

Dewatering
Chemical
Stabilization
Secure Landfill

POTW*

Neutralization
Chemical Treatment
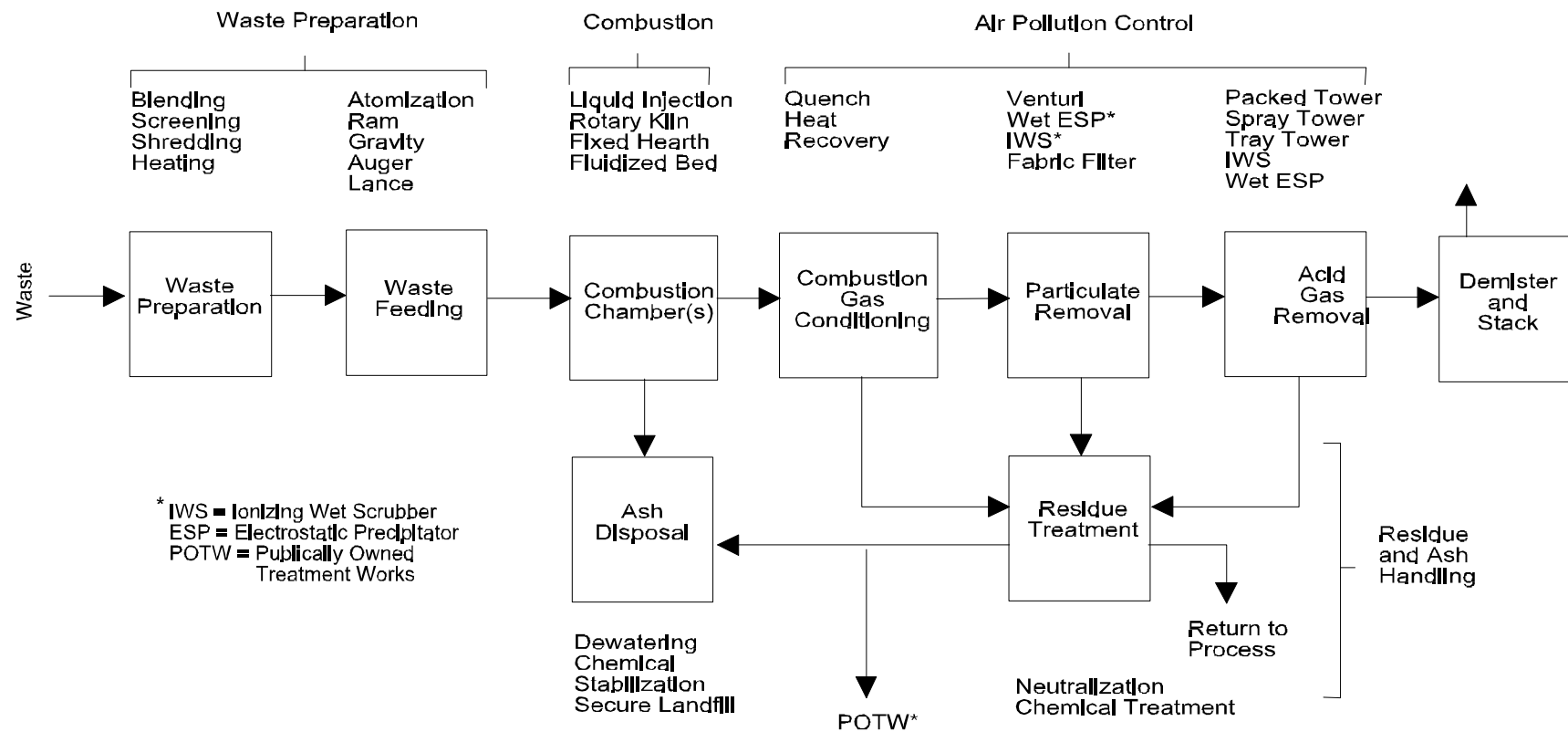
ERG_POM_4351.ds4

Figure 5-15. Typical Process Component Options in a Hazardous Waste Incineration Facility

Source: Reference 125.

Additionally, a few other technologies have been used for incineration of hazardous waste, including ocean incineration vessels and mobile incinerators. These processes are not in widespread use in the United States and are not discussed below.

Liquid Injection Incinerators

Liquid injection combustion chambers are used for pumpable liquid waste, including some low-viscosity sludges and slurries. Liquid injection units are usually simple, refractory-lined cylinders (either horizontally or vertically aligned) equipped with one or more waste burners. The typical capacity of liquid injection units is about 8 to 28 million Btu/hour (8.4 to 29.5 GJ/hour). Figure 5-16 presents a schematic diagram of a typical liquid injection unit.[125,129]

Rotary Kiln Incinerators

Rotary kiln incinerators are used for destruction of solid wastes, slurries, containerized waste, and liquids. Because of their versatility, these units are most frequently used by commercial off-site incineration facilities. Rotary kiln incinerators generally consist of two combustion chambers: a rotating kiln and an afterburner. The rotary kiln is a cylindrical refractory-lined shell mounted on a slight incline. The primary function of the kiln is to convert solid wastes to gases, which occurs through a series of volatilization, destructive distillation, and partial combustion reactions. The typical capacity of these units is about 10 to 60 million Btu/hour (10.5 to 63.3 GJ/hour).

Figure 5-17 presents a schematic diagram of a typical rotary kiln unit. An afterburner is connected directly to the discharge end of the kiln. The afterburner is used to ensure complete combustion of flue gases before their treatment for air pollutants. A tertiary combustion chamber may be added if needed. The afterburner itself may be horizontally or vertically aligned, and functions on much the same principles as the liquid injection unit described above. Both the afterburner and the kiln are usually equipped with an auxiliary fuel-firing system to control the operating temperature.

Aqueous
Waste

Steam

Air

120 - 250%
Excess Air

Discharge
to Quench or
Waste Heat Recovery

Refractory Wall

Auxiliary
Fuel

Spray

Liquid
Waste

Flame

Atomizing
Steam or
Air

Primary
Combustion
Air

2600 °F - 3000° F

0.3 - 2.0 Seconds
Mean Combustion
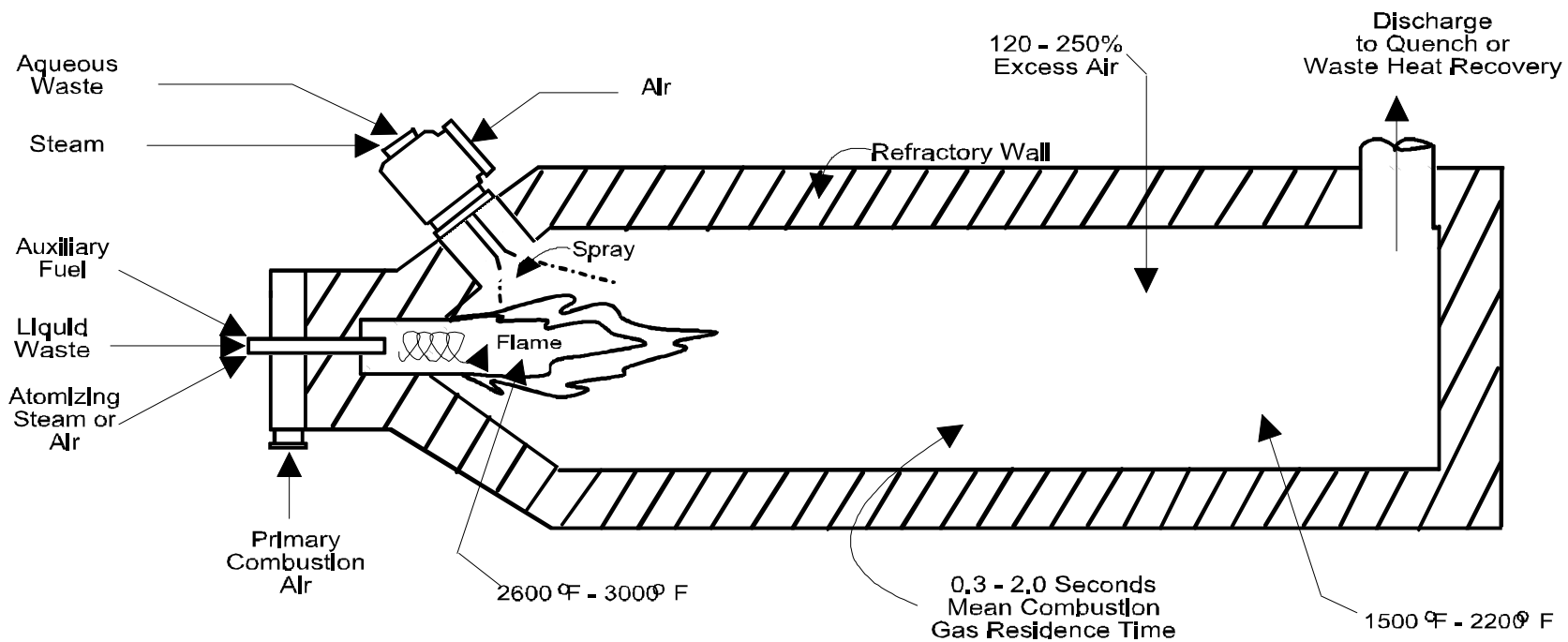Gas Residence Time

1500 °F - 2200° F

ERG_POM_4352.dsr

Figure 5-16. Typical Liquid Injection Combustion Chamber
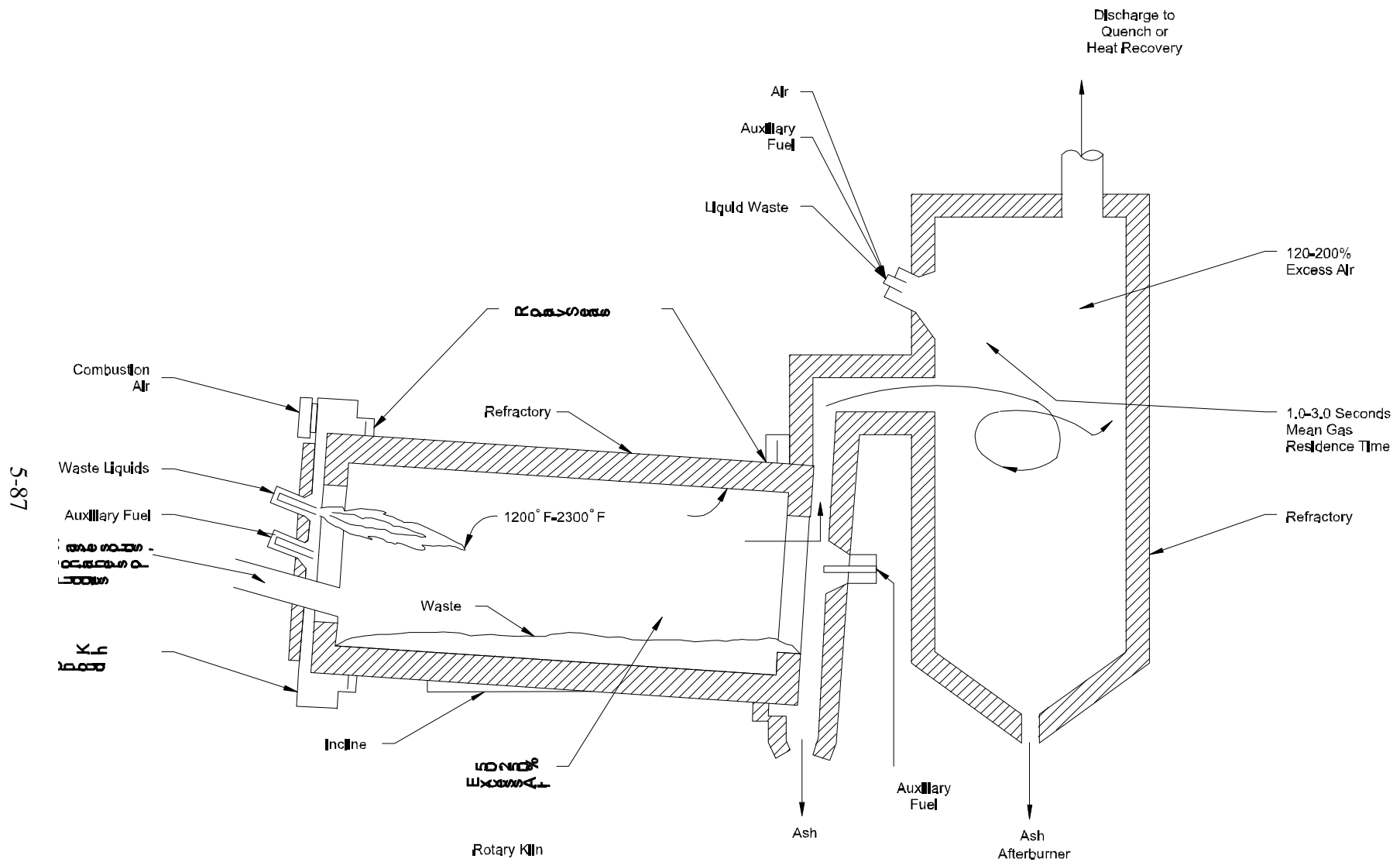
Source: Reference 125.

Figure 5-17. Typical Rotary Kiln/Afterburner Combustion Chamber

Source: Reference 125.

ERG_PB_517.ds4

Fixed-Hearth Incinerators

Fixed-hearth incinerators (also called controlled-air, starved-air, or pyrolytic incinerators) are the third major technology used for hazardous waste incineration. Figure 5-18 presents a schematic diagram of a typical fixed-hearth unit.[125,129] This type of incinerator may be used for the destruction of solid, sludge, and liquid wastes. Fixed-hearth units tend to be of smaller capacity (typically 5 million Btu/hour [5.3 GJ/hour]) than liquid injection or rotary kiln incinerators because of physical limitations in ram feeding and transporting large amounts of waste materials through the combustion chamber.

Fixed-hearth units consist of a two-stage combustion process similar to that of rotary kilns. Waste is ram-fed into the primary chamber and burned at about 50 to 80 percent of stoichiometric air requirements. This starved-air condition causes most of the volatile fraction to be destroyed pyrolitically. The resultant smoke and pyrolysis products pass to the secondary chamber, where additional air and, in some cases, supplemental fuel, is injected to complete the combustion.[125]

Fluidized-Bed Incinerators

Fluidized-bed incinerators (combustors), which were described in Section 5.5.2 of this report, have only recently been applied to hazardous waste incineration. FBCs used to dispose of hazardous waste are very similar to those used to incinerate sewage sludge except for their additional capability of handling liquid wastes.

FBCs are suitable for disposing of combustible solids, liquids, and gaseous wastes. They are not suited for irregular or bulky wastes, tarry solids, or other wastes that leave residues in the bed.[130] Fluidized-bed combustion chambers consist of a single refractory-lined combustion vessel partially filled with inert granular material (e.g., particles of sand, alumina, and sodium carbonate).[125] The typical capacity of this type of incinerator is 45 million Btu/hour (47.5 GJ/hour).

Discharge to
Quench or
Heat Recovery

0.25-2.5 Seconds
Mean Residence Time

Secondary
Chamber
1400° F-2000° F

100-200%
Excess Air

Steam

Auxiliary Fuel or
Liquid Waste

Air

Auxiliary Fuel

Primary
Chamber

50-80%
Excess Air

1200° F-1800° F

Feed
Ram

Refractory

Combustion
Air

Transfer
Ram
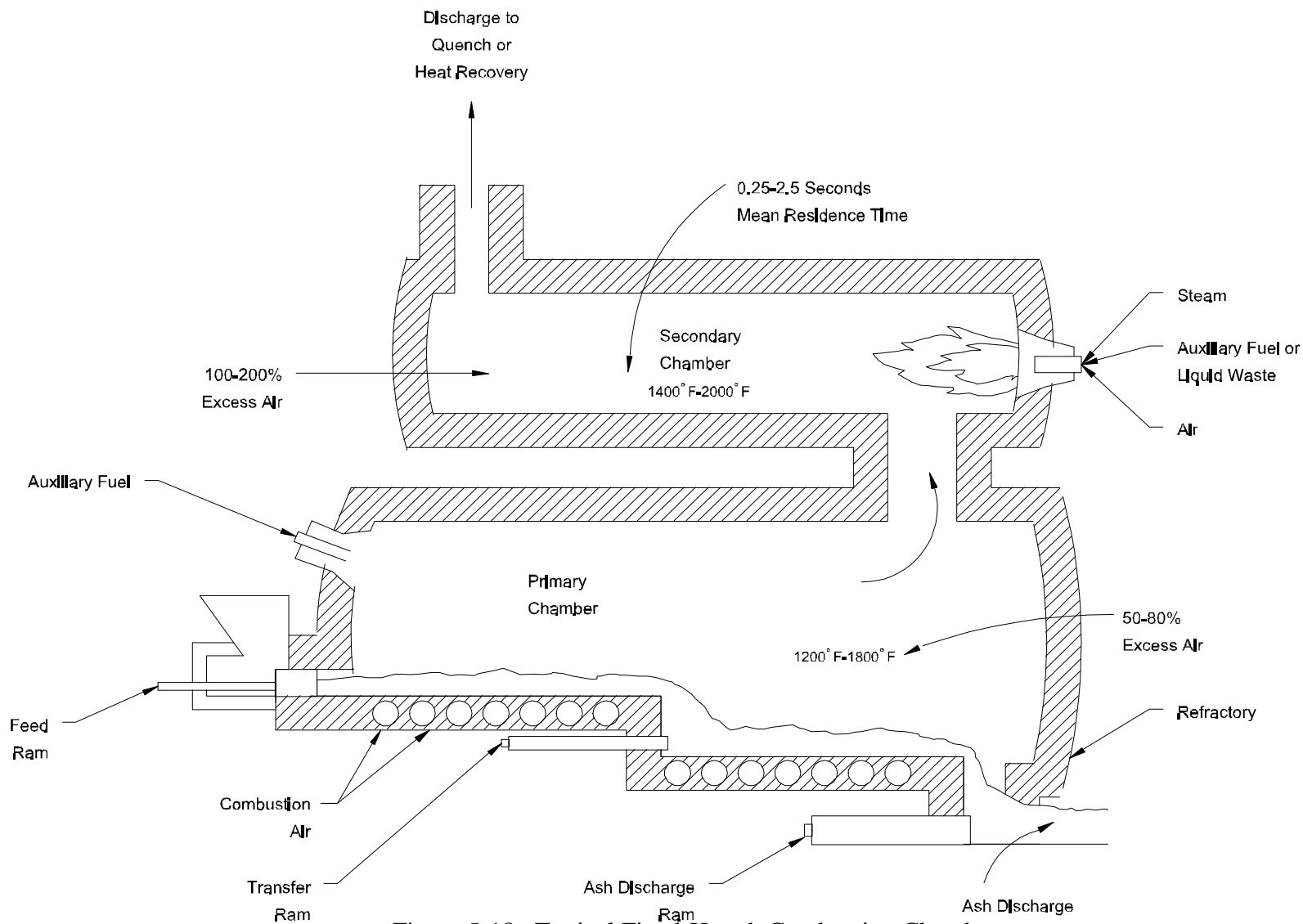
Ash Discharge
Ram

Ash Discharge

Figure 5-18. Typical Fixed-Hearth Combustion Chamber

ERG_PB_518.ds4

Source: Reference 125.

Fume Injection Incinerators

Fume injection incinerators are used exclusively to destroy gaseous or fume wastes. The combustion chamber is comparable to that of a liquid-injection incinerator (Figure 5-16) in that it usually has a single chamber, is vertically or horizontally aligned, and uses nozzles to inject the waste into the chamber for combustion. Waste gases are injected by pressure or atomization through the burner nozzles. Wastes may be combusted solely by thermal or catalytic oxidation.

Emission Control Techniques

The types of incinerators used for hazardous waste combustion are similar to the incinerators used by the other combustion sources discussed earlier in this section. However, the components in the hazardous waste stream vary extensively. The hazardous waste stream may include a variety of liquid, solid, or sludge wastes considered hazardous by RCRA. The hazardous waste stream may also include wastes generated by a variety of sources (e.g., medical, municipal, and sewage sludge).

Controlling lead emissions is partly accomplished by monitoring the temperature of the combustion bed and the feed chlorine content. Lead compounds vaporize at elevated temperatures. The higher the temperature, the larger the fraction of lead vaporized. As the temperature drops, a fraction of the lead condenses. Collection of lead condensed on PM occurs in the APCD. Controlling lead emissions is accomplished using the same type of PM control devices described in Section 5.3.

Chlorine content increases the sensitivity of lead emissions to bed temperature, causing the lead to volatilize at a lower temperature than if there were no chlorine present in the feed. This behavior is due to the high volatility of lead chlorides ($PbCl_2$) versus lead oxides (PbO). Monitoring and limiting the sludge chlorine content allows more lead to condense onto PM for more effective lead emissions control.[60] The PM is then easily captured by ESP or fabric filter control devices.

5.7.3   Emissions

The composition of the hazardous waste varies tremendously in the hazardous waste incineration industry, causing the lead content of the waste stream to vary widely. For example, burning lead-based paint may result in significant lead emissions, while burning halogenated solvents may result in no lead emissions. The lead content of the waste being combusted dictates whether or not significant lead emissions occur.

Because of limited data available on hazardous waste incineration emissions, no emission factors for lead are reported here. However, lead emissions are expected from this source because lead-containing components comprise part of the hazardous waste stream. The variability of the waste is too great to produce any factors that could represent an average incinerator scenario.

5.8   DRUM AND BARREL RECLAMATION

5.8.1   Source Location

Approximately 2,800,000 to 6,400,000 55-gallon drums are incinerated annually in the United States.[131] This estimate is based on the assumptions that there are 23 to 26 incinerators currently in operation, with each incinerator handling 500 to 1,000 drums per day, and operating 5 days a week with 14 days down time for maintenance. The exact locations of these incinerators could not be determined from the available data.

5.8.2   Process Description

Lead emissions have been detected in the stack gases from drum reclamation facilities.[132] These facilities typically consist of a furnace that is used to heat the drums to an elevated temperature in order to destroy any residual materials in the containers. The drums are then repaired, repainted, relined, and sold for reuse. The drums processed at these facilities come from a variety of sources, such as the petroleum and chemical industries.[133]

The furnaces are fired by an auxiliary fuel such as oil or natural gas. The used drums are typically loaded onto a conveyor, which carries them through the heat treatment zone. As the drums proceed through this process, any residual contents, paint, and interior linings are burned off or disintegrated. Lead formation can occur from either the heat treatment of the barrels or from the combustion of the auxiliary fuel.

5.8.3   Emissions

Only one test report was found that measured emissions of specific lead compounds from a drum reclamation facility.[132] The tested facility recycles 55-gallon drums. No information was available concerning the physical or chemical characteristics of the residual waste in the drums or of the auxiliary fuel type used to fire the furnace. The drum furnace consists of a boiler at 1400°F (760°C) and an afterburner at 1600°F (871°C) as an emissions control device. Table 5-24 shows the lead emission factor developed for this facility.

The emission factor for drum reclamation should be used cautiously because the nature of the residual waste product can vary greatly from facility to facility, which will likely affect lead emissions. The type of auxiliary fuel used can also have a significant effect on lead emissions from these facilities.

5.9   SCRAP TIRE INCINERATION

Most facilities that burn scrap tires use the tires to supplement a primary fuel, such as wood. This section addresses only those facilities that burn scrap tires as their sole fuel. The primary purpose of these facilities is to recover energy from the combustion of scrap tires.

5.9.1   Source Location

The EPA's Office of Solid Waste has estimated that approximately 26 million scrap tires were incinerated in the United States in 1990.[134] This equates to approximately

TABLE 5-24. LEAD EMISSION FACTORS FOR DRUM AND BARREL RECLAMATION SOURCES

SCC Number	Emission Source	Control Device	Average Emission Factor in lb/barrel (g/barrel)[a]	Emission Factor Range in lb/barrel (g/barrel)[a]	Emission Factor Rating
3-09-025-01	Drum Reclamation: Drum Burning Furnace	None	3.50×10^{-4} (1.59×10^{-1})	---	E

Source: Reference 132

[a]Emission factors are expressed in lb (g) of pollutant emitted per barrel of waste incinerated.

"---" means data are not available.

11 percent of the 242 million scrap tires generated in 1990. The use of scrap tires as fuel increased significantly during the late 1980s, and is expected to continue to increase.[134]

In December 1991, there were two operational, dedicated tire-to-energy facilities in the United States: the Modesto Energy Project in Westley, California, and the Exter Energy Company in Sterling, Connecticut. In 1993, the Erie Energy Project was built in Lackawanna, New York. The total capacity for all three plants combined could approach almost 25,000,000 tires per year (4,500,000 at the Modesto plant, and 10,000,000 each at the Exter and Erie plants).[135]

5.9.2   Process Description

The following process description is based on the operations at the Modesto Energy Facility in Westley, California. The Modesto facility consists of two whole-tire boilers that generate steam from the combustion of the scrap tires. Tires from a nearby supply pile are fed into a hopper located adjacent to the pile. Tires are then fed into the boilers at a rate of 350 to 400 tires per hour for each boiler. The boilers can accommodate tires as large as 4 feet in diameter made of rubber, fiberglass, polyester, and nylon.

The tires are burned on reciprocating stoker grates in the combustion chamber at the bottom of the boilers. The grate configuration allows air flow above and below the tires, which aids in complete combustion. The boilers are operated above 2,000°F (1,093°C) to ensure complete combustion of organic compounds emitted by the burning tires. The heat generated by the burning of the tires causes the water contained in the pipes of the refractory brickwork that lines the boiler to turn into steam. The high-pressure steam is then forced through a turbine for the generation of power. After exiting the boiler chamber, exhaust gases pass through the large fabric filter.

5.9.3   Emissions

Although no lead emission factors were identified specifically for scrap tire incinerators, this source category is included as a potential source of lead emissions. Lead emission factors for open burning of scrap tires are identified in Section 5.10, "Open Burning of Scrap Tires." The data presented in that section show that lead is a component of tires and, as a result, is emitted from the combustion of tires. It is expected that lead emissions are also present in emissions from incinerators that burn scrap tires. However, because of differences in the combustion and APCD design and operation, emission factors from open burning of scrap tires are not representative of scrap tire incinerators.

5.10   OPEN BURNING OF SCRAP TIRES

5.10.1   Source Location

Open burning of scrap tires can occur at permitted landfills that stockpile scrap tires, at closed landfills that already contain scrap tires, and at illegal dumpsites where tires are discarded. The fires can start by accident or are intentionally set by arsonists, and thus are often unpredictable as to where and when they will occur.

5.10.2   Process Description

Approximately 240 million vehicle tires are discarded annually.[136] Although viable methods for recycling exist, less than 25 percent of discarded tires are recycled; the remaining 175 million are discarded in landfills, stockpiles, or illegal dumps.[136] Although it is illegal in many States to dispose of tires by open burning, fires often occur at tire stockpiles and through illegal burning activities. These fires generate a huge amount of heat and are difficult to extinguish (some tire fires continue for months). Lead is a component of tires and is emitted from the combustion of these tires.

5.10.3   Emissions

Table 5-25 contains emission factors for the open burning of tires.[137] The average emission factor presented represents the average of tests performed on the simulated open burning of chunk (defined as one-quarter or one-sixth of an entire tire) and shredded tires. When estimating emissions from an accidental tire fire, note that emissions from burning tires are generally dependent on the burn rate of the tire.

5.11   CREMATORIES

5.11.1   Source Location

In 1991, there were about 400,000 cremations in more than 1,000 crematories located throughout the United States. Table 5-26 lists the number of crematories located in each State and the estimated number of cremations performed in each State.[138]

5.11.2   Process Description

Crematory incinerators used for human cremation at funeral homes, mortuaries, cemeteries, and crematories are normally of an excess air design. They utilize secondary chamber (afterburner) and primary chamber (ignition) burners fueled by liquified petroleum (LP) gas or natural gas. Burner capacities are generally between 750,000 and 1,500,000 BTUs per hour per burner. Late model units have burner modulation capability to regulate chamber temperatures and conserve fuel. Incineration rates range from 100 to 250 pounds of remains per hour.

Preheating and a minimum secondary chamber temperature, typically ranging from 1,400°F to 1,800°F, may be requirements. Although not suitable for this batch load type of incinerator, the same requirements are occasionally applied to the primary chamber.

TABLE 5-25. LEAD EMISSION FACTORS FOR OPEN BURNING OF SCRAP TIRES

SCC Number	Emission Source	Control Device	Average Emission Factor in lb/ton (kg/Mg)[a]	Emission Factor Range in lb/ton (kg/Mg)[a]	Emission Factor Rating
5-03-002-03	Open Burning of Shredded Automobile Tires	None	2.00×10^{-4} (1.00×10^{-4})	---	C
	Burning of Chunk Automobile Tires	None	6.70×10^{-4} (3.35×10^{-4})	---	C

Source: Reference 137

[a] Emission factors are expressed in lb (kg) of pollutant emitted per ton (Mg) of waste incinerated.

"---" means data are not available.

TABLE 5-26. 1991 U.S. CREMATORY LOCATIONS BY STATE

State	No. of Crematories	No. of Cremations	State	No. of Crematories	No. of Cremations
Alabama	6	1,313	Montana	15	3,234
Alaska	6	860	Nebraska	7	1,710
Arizona	31	13,122	Nevada	12	6,343
Arkansas	13	2,435	New Hampshire	6	2,348
California	142	89,233	New Jersey	16	16,557
Colorado	27	9,537	New Mexico	10	3,140
Connecticut	10	5,528	New York	38	24,625
Delaware	4	1,062	North Carolina	27	6,884
District of Columbia	0	NA	North Dakota	1	NA
Florida	97	59,213	Ohio	42	16,109
Georgia	15	4,786	Oklahoma	10	2,120
Hawaii	8	3,937	Oregon	36	11,272
Idaho	13	2,637	Pennsylvania	46	16,867
Illinois	47	17,557	Rhode Island	5	2,446
Indiana	25	4,743	South Carolina	12	2,422
Iowa	14	3,042	South Dakota	3	NA
Kansas	10	2,029	Tennessee	9	2,451
Kentucky	6	1,548	Texas	39	13,795
Louisiana	5	2,466	Utah	6	1,210
Maine	4	3,469	Vermont	5	1,902
Maryland	18	6,300	Virginia	26	7,738
Massachusetts	13	10,611	Washington	49	18,466
Michigan	40	17,460	West Virginia	6	762
Minnesota	20	7,296	Wisconsin	28	7,293
Mississippi	4	693	Wyoming	3	NA
Missouri	23	6,105			

Source: Reference 138
NA = not available.

The human remains and cremation container, generally made of cardboard or wood, are loaded onto the primary chamber hearth and the primary burner is ignited to begin the cremation process. The remains may be raked at the midpoint of the cremation to uncover unburned material and speed the process. The average cremation takes from 1 1/2 to 3 hours, after which the incinerator is allowed to cool for a period of at least 30 minutes so that the remains can be swept from the hearth.[139]

5.11.3   Emissions

Evaluation tests on two propane-fired crematories at a cemetery in California were conducted through a cooperative effort with the Sacramento Metropolitan Air Quality Management District to determine HAP emissions from a crematory.[140] The units were calibrated to operate at a maximum of 1.45 MMBtu per hour. Emissions testing was performed over a two-week period. Thirty-six bodies were cremated during the test period. The body, cardboard, and wood process rates for each test were reported.

Sampling, recovery, and analysis for lead were performed in accordance with CARB Method 436. Emission factors developed from these data are presented in Table 5-27.

5.12   PULP AND PAPER INDUSTRY

Chemical wood pulping involves the extraction of cellulose from wood by dissolving the lignin that binds the cellulose fibers. Kraft pulping is the major form of chemical wood pulping in the United States, accounting for approximately 85 percent of pulp production[141] and is expected to continue as the dominant pulping process.[142,143] Semi-chemical and acid sulfite pulping constitute 6 and 4 percent of domestic pulp production, respectively.[141]

Four processes associated with the pulp and paper industry have been identified as potential sources of lead emissions: chemical-recovery furnaces, smelt-dissolving tanks, lime kilns, and power boilers. The following sections focus on the pulp mill thermal chemical-recovery processes associated with potential lead emissions. Lead emissions from wood waste

TABLE 5-27. LEAD EMISSION FACTOR FOR CREMATORIES

SCC Number	Emission Source	Control Device	Average Emission Factor in lb/body (kg/body)[a]	Emission Factor Rating
3-15-021-01	Crematory Stack	None	6.62×10^{-5} (3.01×10^{-5})	U

Source: Reference 140

Note: Average weight per body incinerated: body = 141 lb (64 kg); wrapping material = 4 lb (2 kg) cardboard, 3 lb (1.4 kg) wood.

[a] Emission factors are in lb (kg) per body.

and fossil fuel-fired industrial power boilers are not specific to the pulp and paper industry; see Section 5.1.

5.12.1   Kraft Recovery Furnaces and Smelt-Dissolving Tanks

Source Location

The distribution of kraft pulp mills in the United States in 1997 is shown in Table 5-28. Kraft pulp mills are located primarily in the southeast, whose forests provide over 60 percent of U.S. pulpwood.

Process Description

The kraft pulping process involves the cooking or digesting of wood chips at an elevated temperature (340 to 360°F [about 175°C]) and pressure (100 to 135 psig) in white liquor, which is a water solution of sodium sulfide (Na_2S) and sodium hydroxide (NaOH). The lignin that binds the cellulose fibers is chemically dissolved by the white liquor in a tall, vertical digester. This process breaks the wood into soluble lignin and alkali-soluble hemicellulose and insoluble cellulose or pulp. A typical kraft pulping and recovery process is shown in Figure 5-19.

Two types of digester systems are used in chemical pulping: batch and continuous. In a batch digester, the contents of the digester are transferred to an atmospheric tank (usually referred to as a blow tank) after cooking is completed (2 to 6 hours). In a continuous digester, wood chips and white liquor continuously enter the system from the top while pulp is continuously withdrawn from the bottom into a blow tank. In both types of digesters, the entire contents of the blow tank are diluted and pumped to a series of brownstock washers, where the spent cooking liquor is separated from the pulp. The pulp, which may then be bleached, is pressed and dried into the finished product.

TABLE 5-28. DISTRIBUTION OF KRAFT PULP MILLS IN THE
UNITED STATES (1997)

| State	Number of Mills
Alabama	14
Arizona	1
Arkansas	7
California	2
Florida	7
Georgia	12
Idaho	1
Kentucky	2
Louisiana	10
Maine	7
Maryland	1
Michigan	3
Minnesota	2
Mississippi	6
Montana	1
New Hampshire	1
New York	1
North Carolina	6
Ohio	1
Oklahoma	1
Oregon	7
Pennsylvania	3
South Carolina	6
Tennessee	2
Texas	6
Virginia	4
Washington	6
Wisconsin	4
Total	124

Source: Reference 144
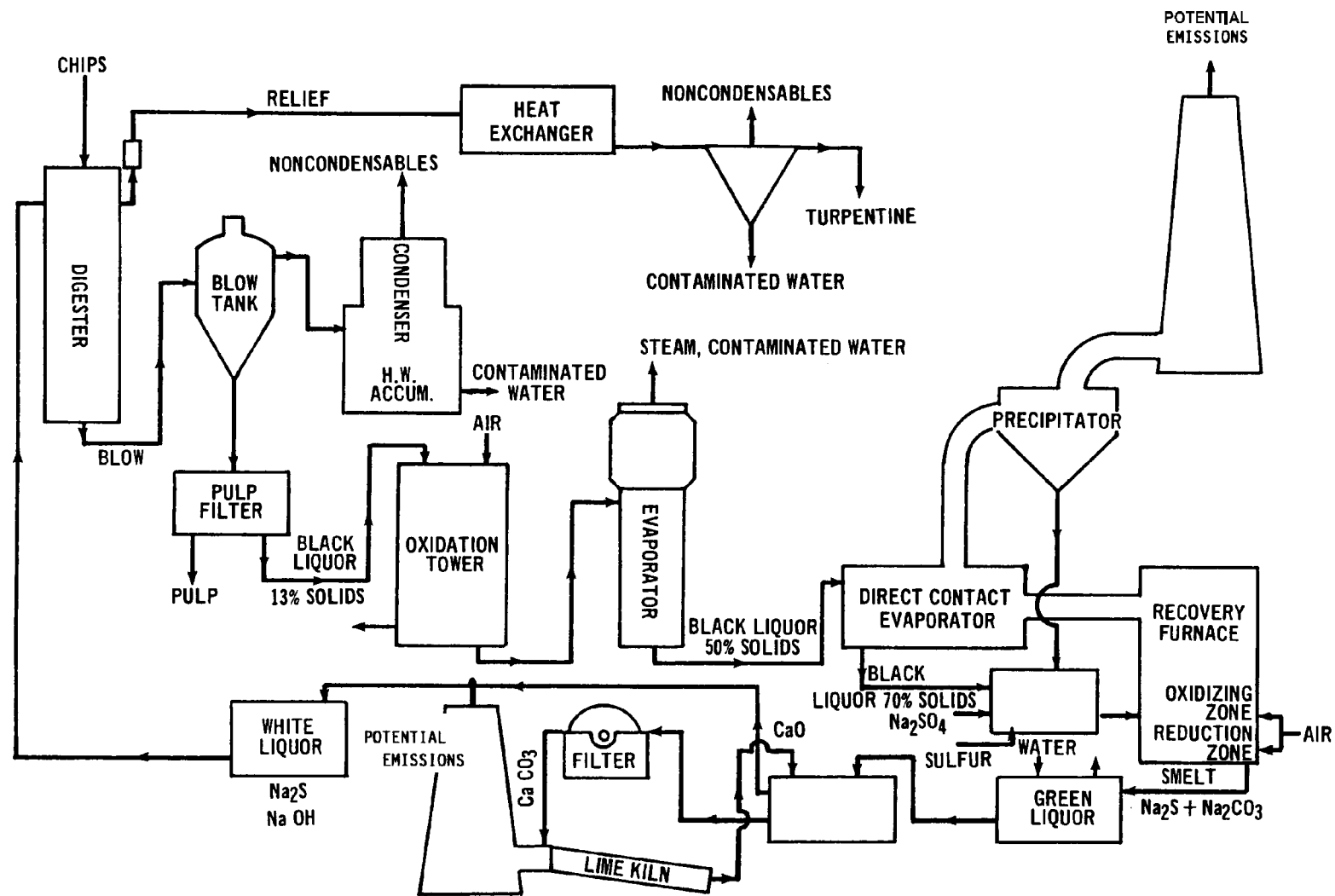
Figure 5-19. Typical Kraft Pulping and Recovery Process

Source: Reference 145.

The balance of the kraft process is designed to recover the cooking chemicals and heat. The diluted spent cooking liquor, or weak black liquor, which is 12 to 18 percent dissolved solids, is extracted from the brownstock washers and concentrated in a multiple-effect evaporator system to about 55 percent solids. The liquor is then further concentrated to 65 percent solids (strong black liquor) in a direct contact evaporator (DCE) or a nondirect contact evaporator (NDCE), depending on the configuration of the recovery furnace in which the liquor is combusted. DCE and NDCE recovery furnace schematics are shown in Figures 5-20 and 5-21, respectively.

In older recovery furnaces, the furnace's hot combustion gases concentrate the black liquor in a DCE prior to combustion. NDCEs include most furnaces built since the early 1970s and modified older furnaces that have incorporated recovery systems that eliminate conventional DCEs. These NDCEs use a concentrator rather than a DCE to concentrate the black liquor prior to combustion. In another type of NDCE system, the multiple-effect evaporator system is extended to replace the direct contact system.

The strong black liquor is sprayed into a recovery furnace with air control to create both reducing and oxidizing zones within the furnace chamber. The combustion of the organics dissolved in the black liquor provides heat for generating process steam and, more importantly, for reducing sodium sulfate (Na_2SO_4) to Na_2S to be reused in the cooking process. Na_2SO_4, which constitutes the bulk of the particulates in the furnace flue gas, is recovered and recycled by an ESP. After combustion, most of the inorganic chemicals present in the black liquor collect as a molten smelt (containing sodium carbonate [Na_2CO_3] and Na_2S) at the bottom of the furnace, where they are continuously withdrawn into a smelt-dissolving tank. Molten smelt in the smelt-dissolving tank is contacted with mill water or weak wash (the filtrate from lime mud washing) to form green liquor.

In addition to straight kraft process liquor, semi-chemical pulping process spent liquor, known as brown liquor, may also be recovered in kraft recovery furnaces. The semi-chemical pulping process is a combination of chemical and mechanical pulping processes
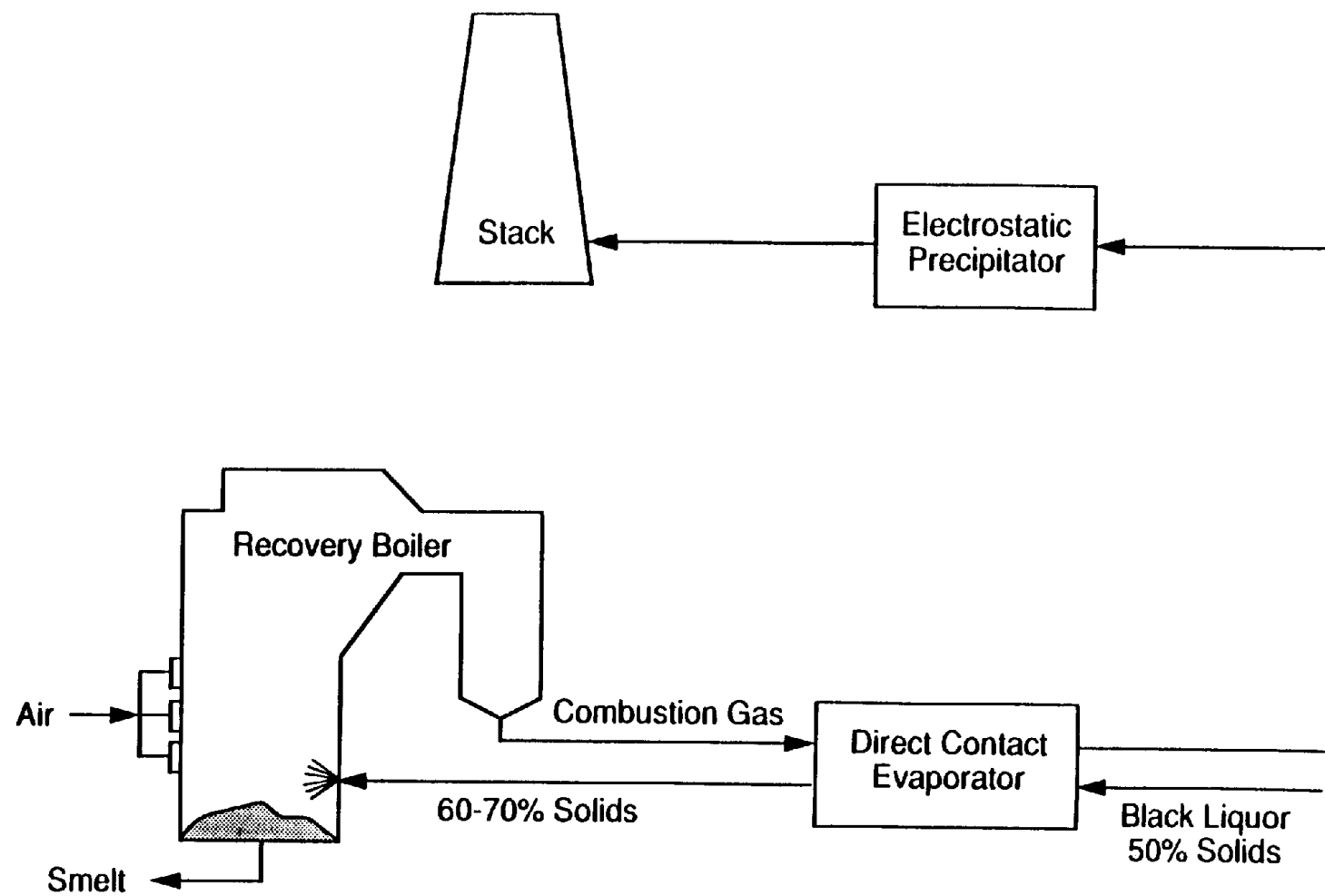
Figure 5-20. Direct Contact Evaporator Recovery Boiler

Source: Reference 146.

Recovery Boiler

Combustion Gas

Electrostatic Precipitator

Stack

Steam

72% Solids

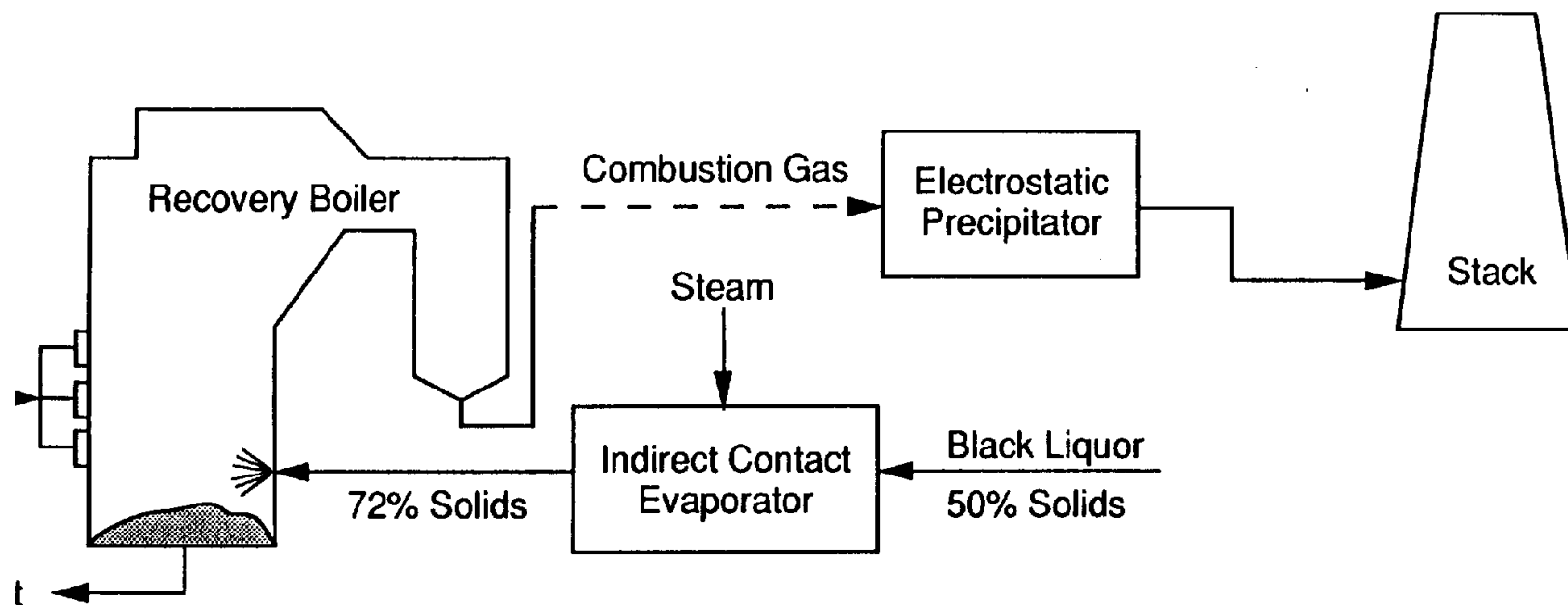Indirect Contact Evaporator

Black Liquor

50% Solids

t

Figure 5-21. Non-direct Contact Evaporator Recovery Boiler

Source: Reference 146.

that was developed to produce high-yield chemical pulps. In the semi-chemical process, wood chips are partially digested with cooking chemicals to weaken the bonds between the lignin and the wood. Oversize particles are removed from the softened wood chips and the chips are mechanically reduced to pulp by grinding them in a refiner. The most common type of semi-chemical pulping is referred to as neutral sulfite semi-chemical (NSSC). The major difference between the semi-chemical process and the kraft/sulfite pulping process is that the semi-chemical digestion process is shorter and wood chips are only partially delignified. Some semi-chemical pulp mills are, as of 1997, using chemical recovery.[144] Also, as mentioned above, some mills combine spent liquor from the on-site semi-chemical process with spent liquor from the adjacent kraft process for chemical recovery.[141]

Particulate emissions from the kraft recovery furnaces consist primarily of Na_2SO_4 and Na_2CO_3, with some sodium chloride. Particulate emissions also contain lead, but only in minute quantities because lead is found as a contaminant in process chemicals and in trace amounts in wood. Particulate control and, therefore, lead control on recovery furnaces is achieved with ESPs, including both wet- and dry-bottom and, to a lesser extent, with scrubbers. Further particulate control is necessary for DCEs equipped with either a cyclonic scrubber or a cascade evaporator because these devices are generally only 20 to 50 percent efficient for particulates.[145] Most often in these cases, an ESP is employed after the DCE for an overall particulate control efficiency range of 85 percent to more than 99 percent. At existing mills, auxiliary scrubbers may be added to supplement older and less efficient primary particulate control devices. No specific data were available in the literature documenting lead control efficiencies for ESPs and scrubbers on kraft black liquor recovery furnaces.

Emissions

Emission factors for lead from kraft recovery furnaces were developed from data provided by the National Council for Air and Stream Improvement, an industry environmental research organization.[147,148] Kraft furnace/control configurations represented included a DCE recovery furnace equipped with an ESP and scrubber in series, a DCE recovery furnace equipped

5-107

with only an ESP, an NDCE recovery furnace equipped with an ESP and scrubber in series, and an NDCE recovery furnace equipped with only an ESP. Emissions data were also provided for smelt-dissolving tanks (3). Lead emission factors for kraft black liquor recovery furnaces and smelt-dissolving tanks are presented in Table 5-29.

5.12.2   Lime Kilns

Source Location

Lime kilns are located at kraft process pulp mills. (See Table 5-28 for kraft pulp mill source locations reported in 1993.)

Process Description

In the kraft process, green liquor from the smelt-dissolving tanks is clarified and reacted with burnt lime (CaO) in a lime slaker. Following a series of causticizing vessels, the resultant white liquor is clarified to yield Na_2S + NaOH (aqueous white liquor) and lime mud or calcium carbonate ($CaCO_3$). The white liquor is recycled to the digestion process and the lime mud is calcined in a lime kiln to regenerate CaO.[146]

A lime kiln is a counter current, inclined tube process heater designed to convert lime mud ($CaCO_3$) to CaO for reuse in the causticizing of kraft liquor. A process flow diagram for a lime kiln is shown in Figure 5-22. The rotary kiln is the most common lime kiln design used in the kraft pulp and paper industry. Rotary lime kilns range from 8 to 13 ft (2.4 to 4.0 m) in diameter, and from 100 to 400 ft (30 to 120 m) in length. Lime kilns predominantly fire natural gas, with some units firing distillate and/or residual fuel oil. Many facilities incinerate non-condensible gases (NCG) from pulping source vents in lime kilns to control total reduced sulfur (TRS) emissions. Temperatures in the kiln can range from 300 to 500°F (150 to 260°C) at the upper or wet end to 2200 to 2400°F (1200 to 1300°C) at the hottest part of the calcination zone near the lower or dry end.[146,149]

TABLE 5-29. LEAD EMISSION FACTORS FOR KRAFT PROCESS RECOVERY FURNACES AND
SMELT DISSOLVING TANKS

SCC Number	Emission Source	Control Device	Average Emission Factor in lb/10^6 ton (kg/10^6 Mg)[a]	Emission Factor Range in lb/10^6 ton (kg/10^6 Mg)[a]	Emission Factor Rating
3-07-001-04	Direct Contact Evaporator Kraft Recovery Furnace	ESP, ESP/Wet Scrubber	9.5×10^1 (4.8×10^1)	---	D
3-07-001-10	Nondirect Contact Evaporator Kraft Recovery Furnace	ESP, ESP/Wet Scrubber	1.2×10^2 (5.9×10^1)	---	D
3-07-001-05	Smelt Dissolving Tank	Demister, Venturi Scrubber	2.3×10^1 (1.2×10^1)	---	D

Source: Reference 147,148

[a]Emission factors are in lb (kg) of pollutant emitted per million tons (Mg) of black liquor solids (BLS) processed.

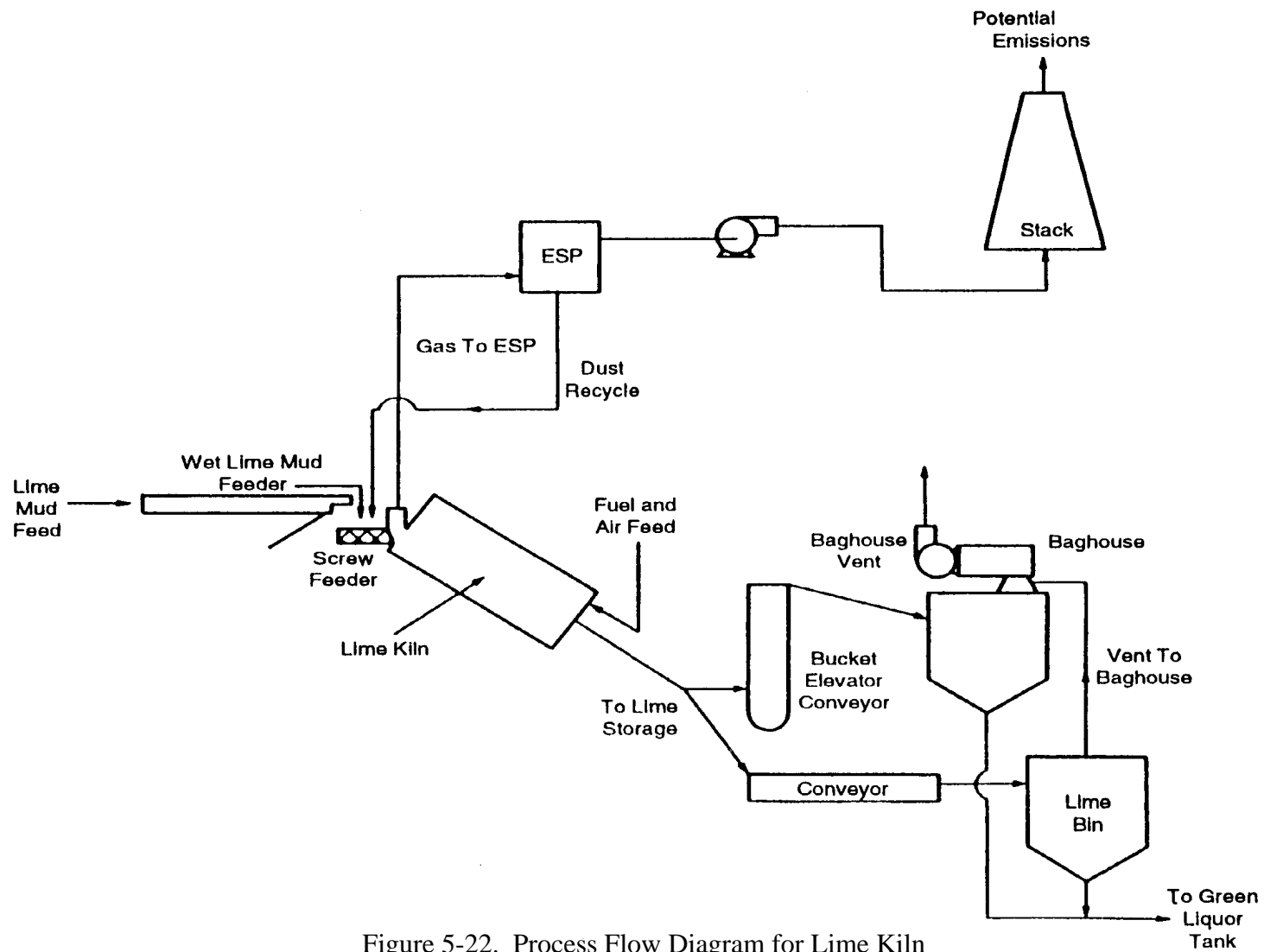"---" means data are not available.

ESP = Electrostatic Precipitator.

Figure 5-22. Process Flow Diagram for Lime Kiln

Source: Reference 146.

Emissions of concern from lime kilns include PM, largely in the form of calcium salts; some of the PM also contains lead. Emissions of lead from lime kilns are likely due to the lead content of the lime mud with some contribution from the combustion of fossil fuel (natural gas or fuel oil). The most common PM control technologies used on lime kilns are scrubbers (some ESPs are also used). Scrubbers on lime kilns use either fresh water or clean condensates from pulping sources as a scrubbing medium. Small amounts of caustic solution may be added to the scrubbing solution to scrub TRS & SO_2. Lime kiln scrubber designs include impingement, venturi, and cyclonic scrubbers.[150]

Emissions

Lead emission factors for uncontrolled and scrubber-controlled lime kilns are presented in Table 5-30.

5.12.3   Sulfite Recovery Furnaces

Source Location

Sulfite recovery furnaces are located at sulfite process pulp mills. Table 5-31 shows the distribution of sulfite pulp mills in the United States in 1997 according to information compiled in support of EPA's pulp and paper industry MACT standard development.

Process Description

Although not as commonplace, the acid sulfite pulp production process is similar to the kraft process except that different chemicals are used for cooking. Sulfurous acid is used in place of a caustic solution to dissolve wood lignin. To buffer the cooking solution, a bisulfite of sodium, magnesium, calcium, or ammonium is used. Digestion occurs under high temperature and pressure, as in the kraft process, in either batch mode or continuous digesters. Following digestion and discharge of the pulp into an atmospheric blow pit or dump tank, the spent sulfite

TABLE 5-30. LEAD EMISSION FACTORS FOR LIME KILNS

SCC Number	Emission Source	Control Device	Average Emission Factor in lb/ton (kg/Mg)	Emission Factor Range in lb/ton (kg/Mg)	Emission Factor Rating	Reference
3-07-001-06	Lime Kiln	None	1.09×10^{-4} (5.44×10^{-5})[a]	1.86×10^{-5} - 1.21×10^{-4}	U	151
		Scrubber	1.41×10^{4} (7.07×10^{3})[b]	---	D	147,148

[a] Emission factors in lb (kg) per air dry ton (Mg) of pulp produced.
[b] Emission factors in lb (kg) per million tons (Mg) of calcium oxide (lime) produced.

"---" means data are not available.

TABLE 5-31. DISTRIBUTION OF SULFITE PULP MILLS IN THE UNITED STATES
(1997)

State	Number of Mills
Alaska	1
Florida	1
Maine	1
New York	1
Pennsylvania	1
Washington	5
Wisconsin	4
Total	14

Source: Reference 144

liquor, known as red liquor, may be treated and discarded, incinerated, or sent through a recovery process for recovery of heat and chemicals. Additionally, chemicals can be recovered from gaseous streams such as those from red stock washers. The cost of the soluble bases, with the exception of calcium, makes chemical recovery economically feasible.[141,145] A simplified process schematic of magnesium-based sulfite pulping and chemical recovery is shown in Figure 5-23.

Chemical recovery in the sulfite process involves the concentration of weak red liquor in multiple effect evaporators and DCEs to strong red liquor (55 to 60 percent solids). This liquor is sprayed into a furnace and burned, producing steam for mill processes. When magnesium-base liquor is burned, magnesium oxide is recovered from the flue gas in a multicyclone. The collected magnesium oxide is then water-slaked and used as circulation liquor in a series of venturi scrubbers designed to absorb SO_2 from the flue gas to form bisulfite solution for use in the cook cycle.

Figure 5-23. Process Diagram for Magnesium-Based Sulfite Pulping and Chemical Recovery

Source: Reference 145.

Several processes for chemical recovery from sodium-base liquor are based upon the combustion of concentrated liquor in a kraft-type recovery furnace. The resultant smelt is similar in composition to that produced by combustion of kraft liquor. The commercial approaches to convert sodium-base smelt chemicals into regenerated cooking liquor include Sivola-Lurgi, Tampella, Storm, Mead, and Rayonier.[152] Sulfite mills that do not practice chemical recovery require an acid plant to fulfill total sulfite demand. This is accomplished by rotary or spray sulfur burners equipped with heat exchangers and SO_2-absorbing scrubbers.

Emissions

As with the kraft process, lead exists only as a contaminant in process chemicals and in trace amounts in wood and is, therefore, found in minute quantities. Only one emission factor was available in the literature for lead from an uncontrolled sulfite recovery furnace. The lead emission factor is presented in Table 5-32.

5.13   PORTLAND CEMENT MANUFACTURING

Two processes, the wet and dry processes, can be used to manufacture Portland cement. Based on 1990 U.S. cement kiln capacity data, an estimated 68 percent of Portland cement is manufactured using the dry process. A description of the wet and dry processes and the emissions resulting from the various operations is presented below.

5.13.1   Source Location

In 1990, there were a total of 212 U.S. cement kilns with a combined total clinker capacity of $81.1x10^6$ tons ($73.5x10^6$ Mg). Of this total, 11 kilns with a combined capacity of $2.0x10^6$ tons ($1.8x10^6$ Mg) were inactive. More than 30 raw materials are used to manufacture Portland cement. These materials can be classified into four basic classes of raw materials: calcarious, siliceous, argillaceous, and ferriferous. The 201 active kilns had a clinker capacity of

TABLE 5-32. LEAD EMISSION FACTORS FOR SULFITE PROCESS RECOVERY FURNACES

SCC Number	Emission Source	Control Device	Average Emission Factor in lb/10^6 ton (kg/10^6 Mg)[a]	Emission Factor Range in lb/10^6 ton (kg/10^6 Mg)[a]	Emission Factor Rating
3-07-002-22	Sulfite Recovery Furnace	None	1.70×10^1 (8.5)	---	D

Source: Reference 147,148

[a]Emission factors in lb (kg) per million tons (Mg) of red liquor solids (RLS) processed.

"---" means data are not available.

79.1x10^6 tons (71.8x10^6 Mg). The name, location, and clinker capacity of each kiln is presented in Table 5-33.

5.13.2 <u>Process Description</u>

Figure 5-24 presents a basic flow diagram of the Portland cement manufacturing process. The process can be divided into four major steps: raw material acquisition and handling, kiln feed preparation, pyroprocessing, and finished cement grinding.

The initial step in the production of Portland cement manufacturing is raw materials acquisition. Calcium, which is the element of highest concentration in Portland cement, is obtained from a variety of calcareous raw materials, including limestone, chalk, marl, sea shells, aragonite, and an impure limestone known as "natural cement rock." The other raw materials--silicon, aluminum, and iron--are obtained from ores and minerals such as sand, shale, clay, and iron ore. Lead is expected to be present in the ores and minerals extracted from the earth. The only potential source of lead emissions from raw material acquisition would be due to wind-blown particulate-containing lead from the quarry operations. Lead emissions are expected to be negligible from these initial steps in Portland cement production.

The second step involves preparation of the raw materials for pyroprocessing (thermal treatment). Raw material preparation includes a variety of blending and sizing operations designed to provide a feed with appropriate chemical and physical properties. The raw material processing differs for wet processes and dry processes. At facilities where the dry process is used, the moisture content in the raw material, which can range from less than 1 percent to greater than 50 percent, is reduced to less than 1 percent. Lead emissions can occur during this drying process, but are anticipated to be very low because the drying temperature is much below the boiling point of lead. At some facilities, heat for drying is provided by the exhaust gases from the pyroprocessor. At facilities where the wet process is used, water is added to the raw material during the grinding step, thereby producing a pumpable slurry containing approximately 65 percent solids.

TABLE 5-33. PORTLAND CEMENT PRODUCTION FACILITIES

Company and location	No./type of kiln	Clinker capacity[a]	
		10^3 Mg/yr	10^3 tons/yr
Alamo Cement Co.			
San Antonio, TX	1-Dry	680	750
Allentown Cement Co., Inc.			
Blandon, PA	2-Dry	844	930
Armstrong Cement & Sup. Co.			
Cabot, PA	2-Wet	281	310
Ash Grove Cement Co.			
Nephi, UT	1-Dry	544	600
Louisville, NE	2-Dry	872	961
Durkee, OR	1-Dry	454	500
Foreman, AR	3-Wet	857	945
Montana City, MT	1-Wet	254	280
Chanute, KS	2-Wet	450	496
Inkom, ID	2-Wet	191	210
Blue Circle, Inc.			
Ravena, NY	2-Wet	1,390	1,532
Atlanta, GA	2-Dry	555	612
Tulsa, OK	2-Dry	544	600
Calera, AL	2-Dry	544	600
Boxcrow Cement			
Midlothian, TX	1-Dry	907	1,000
Calaveras Cement Co.			
Redding, CA	1-Dry	591	651
Tehachapi, CA	1-Wet	386	425
California Portland Cement			
Mojave, CA	1-Dry	943	1,039
Colton, CA	2-Dry	680	750
Rillito, AZ	4-Dry	966	1,065
Capitol Cement Corporation			
Martinsburg, WV	3-Wet	746	822
Capitol Aggregates, Inc.			
San Antonio, TX	1-Dry/1-Wet	456/319	503/352
Carlow Group			
Zanesville, OH	2-Wet	547	603
Centex			
Laramie, WY	1-Dry	418	461
La Salle, IL	1-Dry	372	410
Fernley, NV	2-Dry	376	415

TABLE 5-33. PORTLAND CEMENT PRODUCTION FACILITES (CONTINUED)

Company and location	No./type of kiln	Clinker capacity[a]	
		10^3 Mg/yr	10^3 tons/yr
Continental Cement Co., Inc.			
Hannibal, MO	1-Wet	544	600
Dixon-Marquette			
Dixon, IL	4-Dry	475	524
Dragon Products Company			
Thomaston, ME	1-Wet	413	455
Essroc Materials			
Nazareth, PA	1-Dry	874	963
Speed, IN	2-Dry	863	951
Bessemer, PA	1-Dry/1-Wet	295/191	325/211
Frederick, MD	2-Wet	336	370
Logansport, IN	2-Wet	367	404
Florida Crushed Stone			
Brooksville, FL	1 - Dry	518	571
Giant Cement Company			
Harleyville, SC	4 - Wet	789	870
Gifford-Hill & Co., Inc.			
Harleyville, SC	1 - Dry	560	617
Oro Grande, CA	7 - Dry	1,041	1,148
Riverside, CA	2 - Dry	100	110
Glens Falls Cement Co.			
Glens Falls, NY	1-Dry	450	495
Hawaiian Cement Company			
Ewa Beach, HI	1-Dry	239	263
Heartland Cement Company			
Independence, KS	4-Dry	305	336
Hercules Cement Company			
Stockertown, PA	3-Dry	656	723

TABLE 5-33. PORTLAND CEMENT PRODUCTION FACILITES (CONTINUED)

| Company and location | No./type of kiln | Clinker capacity[a] | |
		10^3 Mg/yr	10^3 tons/yr
Holnam, Inc.			
Theodore, AL	1-Dry	1,308	1,442
Clarksville, MO	1-Wet	1,190	1,312
Holly Hill, SC	2-Wet	991	1,092
Mason City, IA	2-Dry	806	888
Florence, CO	3-Wet	780	860
Fort Collins, CO	1-Dry	448	494
Dundee, MI	2-Wet	880	970
Artesia, MS	1-Wet	457	504
Seattle, WA	1-Wet	429	473
Three Forks, MT	1-Wet	283	312
Ada, OK	2-Wet	544	600
Tijeras, NM	2-Dry	448	494
Saratoga, AR	2-Wet	335	369
Morgan, UT	2-Wet	298	328
Independent Cement Corp.			
Catskill, NY	1-Wet	464	512
Hagerstown, MD	1-Dry	452	498
Kaiser Cement Corp.			
Permanente, CA	1-Dry	1,452	1,600
Keystone Cement Company			
Bath, PA	2-Wet	546	602
Kosmos Cement Co.			
Louisville, KY	1-Dry	657	724
Pittsburgh, PA	1-Wet	357	394
LaFarge Corporation			
New Braunfels, TX	1-Dry	865	954
Buffalo, IA	1-Dry	778	858
Demopolis, AL	1-Dry	655	722
Grand Chain, IL	2-Dry	1,076	1,186
Alphena, MI	5-Dry	1,773	1,954
Whitehall, PA	3-Dry	689	760
Sugar Creek, MO	2-Dry	437	482
Paulding, OH	2-Wet	445	490
Fredonia, KS	2-Wet	347	382
Lehigh Portland Cement			
Mason City, IA	1-Dry	689	760
Leeds, AL	1-Dry	591	651
Cementon, NY	1-Wet	506	558
Union Bridge, MD	4-Dry	900	992
Mitchell, IN	3-Dry	689	760
York, PA	1-Wet	90	99
Waco, TX	1-Wet	73	81

TABLE 5-33. PORTLAND CEMENT PRODUCTION FACILITES (CONTINUED)

Company and location	No./type of kiln	Clinker capacity[a]	
		10^3 Mg/yr	10^3 tons/yr
Lone Star Industries			
Cape Girardeau, MO	1-Dry	1,002	1,104
Greencastle, IN	1-Wet	649	715
Oglesby, IL	1-Dry	422	465
Pryor, OK	3-Dry	623	687
Nazareth, PA	4-Dry	565	623
Sweetwater, TX	3-Dry	449	495
Medusa Cement Co.			
Charlevoix, MI	1-Dry	1,237	1,364
Clinchfield, GA	1-Dry/1-Wet	508/187	560/206
Wampum, PA	3-Dry	638	703
Mitsubishi Cement Corp.			
Lucerne Valley, CA	1-Dry	1,514	1,669
Monarch Cement Company			
Humboldt, KS	3-Dry	611	674
Des Moines, IA	2-Wet	272	300
National Cement Company			
Ragland, AL	1-Dry	767	845
Natl. Cement Co. of California			
Lebec, CA	1-Dry	590	650
North Texas Cement			
Midlothian, TX	3-Wet	816	900
Phoenix Cement Company			
Clarkdale, AZ	3-Dry	640	705
Rinker Portland Cement Corp.			
Miami, FL	2-Wet	512	564
River Cement Company			
Festus, MO	2-Dry	1,070	1,179
RMC Lonestar			
Davenport, CA	1-Dry	726	800
Roanoke Cement Company			
Cloverdale, VA	5-Dry	1,013	1,117
Signal Mountain Cement Co.			
Chattanooga, TN	2-Wet	408	450
South Dakota Cement			
Rapid City, SD	1-Dry/2-Wet	408/287	450/316

TABLE 5-33. PORTLAND CEMENT PRODUCTION FACILITES (CONTINUED)

Company and location	No./type of kiln	Clinker capacity[a]	
		10^3 Mg/yr	10^3 tons/yr
Southdown, Inc.			
Victorville, VA	2-Dry	1,406	1,550
Brooksville, FL	2-Dry	1,089	1,200
Knoxville, TN	1-Dry	544	600
Fairborn, OH	1-Dry	553	610
Lyons, CO	1-Dry	408	450
Odessa, TX	2-Dry	499	550
St. Mary's Peerless Cement Co.			
Detroit, MI	1-Wet	533	610
Tarmac Florida, Inc.			
Medley, FL	3-Wet	933	1,028
Texas Industries			
New Braunfels, TX	1-Dry	689	759
Midlothian, TX	4-Wet	1,139	1,256
Texas-Lehigh Cement Co.			
Buda, TX	1-Dry	895	987
Total capacity reported	135-Dry/79-Wet	73,532	81,056

Source: Reference 153

[a] Kilns reported as inactive in 1990:

|			Clinker capacity	
			10^3 Mg/year	10^3 tons/year
Ash Grove Cement	Foreman, AR	1 kiln	246	271
California Portland Cement	Rillito, AZ	2 kilns	245	270
Holnam, Inc.	Florence, CO	2 kilns	334	368
Lone Star Industries	Sweetwater, TX	1 kiln	150	165
Medusa Cement Company	Clinchfield, GA	1 kiln	187	206
Monarch Cement Company	Des Moines, IA	2 kilns	272	300
Tarmac Florida	Medby, FL	2 kilns	334	368
		Total active capacity	71,764	79,108
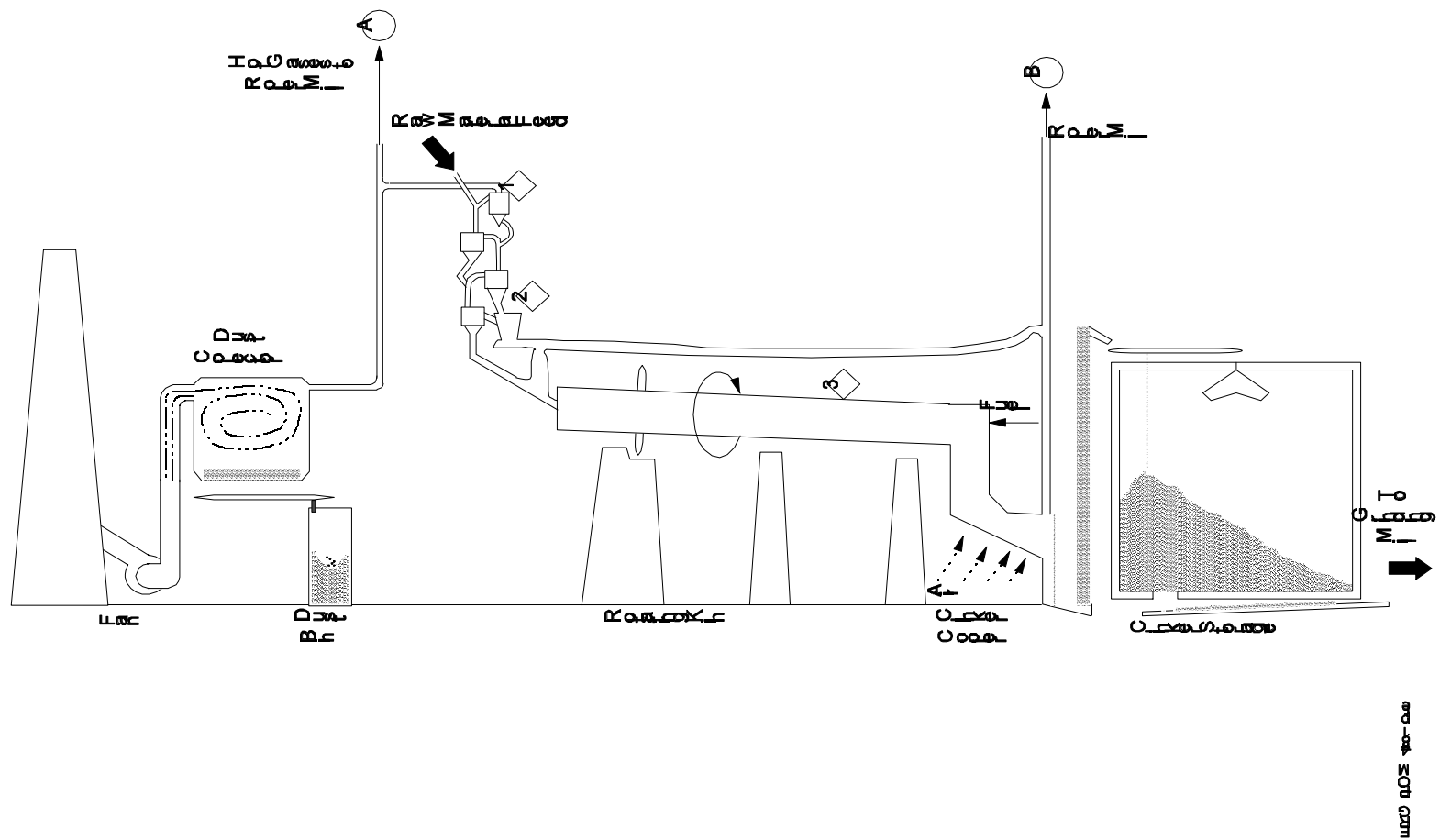
Figure 5-24. Process Flow Diagram of Portland Cement Manufacturing Process

Source: Reference 154,155.

Pyroprocessing of the raw material is carried out in the kiln, which is the heart of the Portland cement manufacturing process. During pyroprocessing, the raw material is transformed into clinkers, which are gray, glass-hard, spherically shaped nodules that range from 0.125 to 2.0 in. (0.32 to 5.1 cm) in diameter. The chemical reactions and physical processes that take place during pyroprocessing include the following:

1. Evaporation of uncombined water from raw materials as material temperature increases to 212°F (100°C).

2. Dehydration as the material temperature increases from 212°F (100°C) to approximately 800°F (430°C) to form the oxides of silicon, aluminum, and iron.

3. Calcination, during which carbon dioxide (CO_2) is evolved between 1,650°F (900°C) and 1,800°F (982°C) to form calcium oxide.

4. Reaction of the oxides in the burning zone of the rotary kiln to form cement clinker at temperatures of about 2,750°F (1,510°C).

The rotary kiln is a long, cylindrical, slightly inclined, refractory-lined furnace. The raw material mix is introduced into the kiln at the elevated end, and the combustion fuels are usually introduced into the kiln at the lower end in a countercurrent manner. The rotary motion of the kiln transports the raw material from the elevated end to the lower end. Fuel such as coal or natural gas, or occasionally oil, is used to provide energy for calcination. Lead is present in coal and oil. Use of other fuels such as chipped rubber, petroleum coke, and waste solvents is becoming increasingly popular.

Combustion of fuel during the pyroprocessing step contributes to potential lead emissions. Lead may also be present in the waste-derived fuel mentioned above. Because lead evaporates at 2,950°F (1,620°C), which is above normal kiln operating temperatures, much of the lead present in the raw materials is expected to be incorporated into the clinker. Most of the lead that is volatilized in the hot end of the kiln condenses onto PM upon cooling and is either removed in the downstream equipment, such as the APCD, or removed in the bypass gases or the preheater.

Pyroprocessing can be carried out using one of five different processes: wet, semi-dry, dry, dry with a preheater, and dry with a preheater/precalciner. These processes essentially accomplish the same physical and chemical steps described above. The last step in the pyroprocessing is the cooling of the clinker. This step recoups up to 30 percent of the heat input to the kiln system, locks in desirable product qualities by freezing mineralogy, and makes it possible to handle the cooled clinker with conventional conveying equipment. Finally, after the cement clinker is cooled, a sequence of blending and grinding operations is carried out to transform the clinker into finished Portland cement.

5.13.3   Emission Control Techniques

With the exception of the pyroprocessing operations, the emission sources in the Portland cement industry can be classified as either process emissions or fugitive emissions. The primary pollutant resulting from the fugitive sources is PM, which contains a fraction of lead. The control measures used for these fugitive dust sources are comparable to those used throughout the mineral products industries.

Process fugitive emission sources include materials handling and transfer, raw milling operations in dry process facilities, and finish milling operations. Typically, particulate emissions from these processes are captured by a ventilation system vented to fabric filters. Because the dust from these units is returned to the process, they are considered to be process units as well as air pollution control devices. The industry uses shaker, reverse air, and pulse jet filters, as well as some cartridge units, but most newer facilities use pulse jet filters. For process fugitive operations, the different systems are reported to achieve typical outlet PM loadings of 0.02 grains per actual cubic foot (gr/acf) (45 milligrams per cubic meter [mg/m^3]). Because the lead is in particle form, the performance of these systems relative to lead control is expected to be equivalent to this overall particulate performance. However, no data are available on lead performance of fugitive control measures.

In the pyroprocessing units, PM emissions are controlled by fabric filters (reverse air, pulse jet, or pulse plenum) and ESPs. The reverse air fabric filters and ESPs typically used to

control kiln exhausts are reported to achieve outlet PM loadings of 0.02 gr/acf (45 mg/m^3). Clinker cooler systems are controlled most frequently with pulse jet or pulse plenum fabric filters. A few gravel bed filters have been used on clinker coolers.

5.13.4   Emissions

Lead emission factor data are presented in Table 5-34. The principal source of lead emissions is expected to be from the kiln. The majority of the lead input from the raw materials and fuels is incorporated into the clinker. Lead volatilized from the kiln is either removed in the bypass gases, the preheater, or the APCD. Small quantities of emissions would be expected during raw materials processing and mixing in the form of fugitive dust containing naturally occurring quantities of lead compounds in raw materials.

Processing steps that occur after the calcining process in the kiln would be expected to be a much smaller source of emissions than the kiln. Emissions resulting from all processing steps include particulate matter. Additionally, emissions from the pyroprocessing step include other products of fuel combustion such as sulfur dioxide (SO_2), nitrogen oxides (NO_x), carbon dioxide (CO_2), and carbon monoxide (CO). Carbon dioxide from the calcination of limestone will also be present in the flue gas.

TABLE 5-34. LEAD EMISSION FACTORS FOR PORTLAND CEMENT MANUFACTURING FACILITIES

SCC Number	Emission Source	Control Device	Average Emission Factor lb/ton (kg/Mg)	Emission Factor Range lb/ton (kg/Mg)	Emission Factor Rating	Reference
3-05-006-06	Dry Process Kilns	FF	7.50×10^{-5} $(3.75 \times 10^{-5})^a$	---	D	155
		ESP	7.10×10^{-4} $(3.55 \times 10^{-4})^a$	---	D	155
		None	1.20×10^{-1} $(6.00 \times 10^{-2})^b$	---	U	23
3-05-006-13	Dry Process Raw Material Grinding or Drying	None	4.00×10^{-2} $(2.00 \times 10^{-2})^a$	---	U	23
3-05-006-17	Dry Process Clinker Grinding	None	4.00×10^{-2} $(2.00 \times 10^{-2})^b$	---	U	23
3-05-006-22	Dry Process Preheater Kilns	FF	7.50×10^{-5} $(3.75 \times 10^{-5})^a$	---	D	155
		ESP	7.10×10^{-4} $(3.55 \times 10^{-4})^a$	---	D	155
3-05-006-23	Dry Process Preheater/ Precalcinator Kiln	FF	7.50×10^{-5} $(3.75 \times 10^{-5})^a$	---	D	155
		ESP	7.10×10^{-4} $(3.55 \times 10^{-4})^a$	---	D	155
3-05-007-06	Wet Process Kilns	ESP	7.10×10^{-4} $(3.55 \times 10^{-4})^a$	---	D	155
		FF	7.50×10^{-5} $(3.75 \times 10^{-5})^a$	---	D	155
		None	1.00×10^{-1} $(5.00 \times 10^{-2})^b$	---	U	23

TABLE 5-34. LEAD EMISSION FACTORS FOR PORTLAND CEMENT MANUFACTURING FACILITIES (CONTINUED)

SCC Number	Emission Source	Control Device	Average Emission Factor lb/ton (kg/Mg)	Emission Factor Range lb/ton (kg/Mg)	Emission Factor Rating	Reference
3-05-007-17	Wet Process Clinker Grinding	None	2.00×10^{-2} $(1.00 \times 10^{-2})^{b}$	---	U	23

[a] Emission factors are expressed in lb (kg) of pollutant emitted per ton (Mg) of cement produced.
[b] Emission factors are expressed in lb (kg) of pollutant emitted per ton (Mg) of clinker produced.

"---" means data are not available.

ESP = Electrostatic Precipitator.
FF = Fabric Filter.